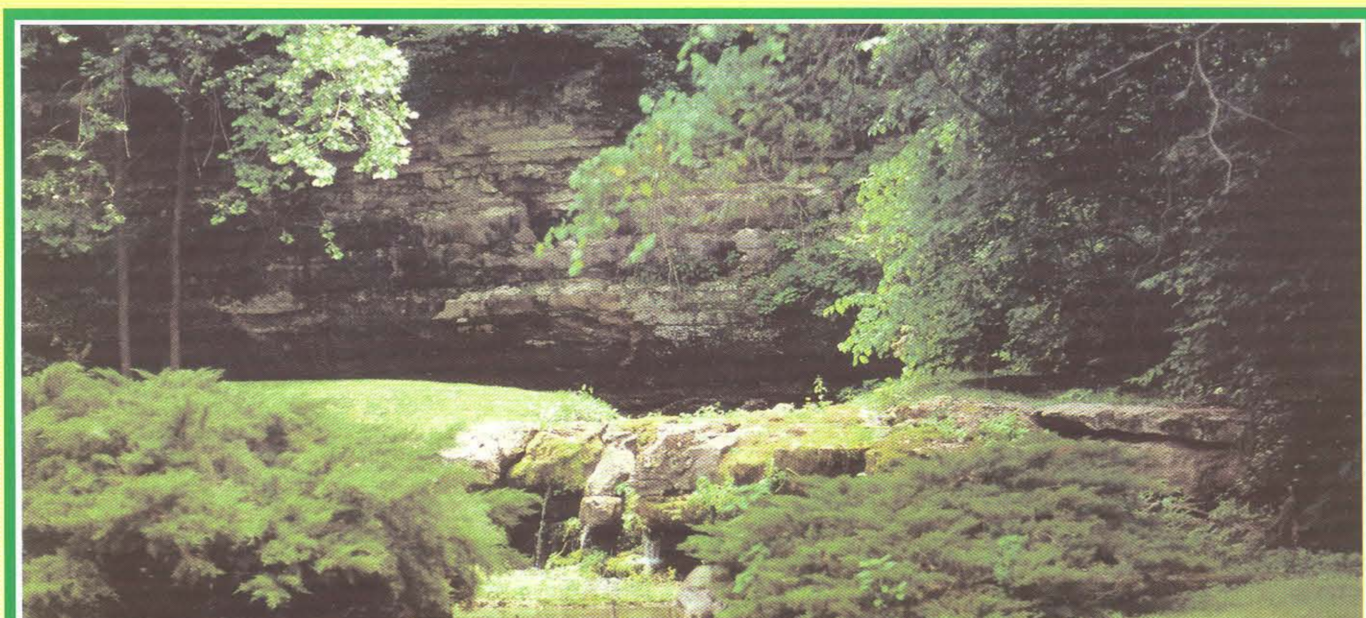
Water Resources Report Number 47
MISSOURI STATE WATER PLAN SERIES
VOLUME III

Missouri Water Quality Assessment



MISSOURI DEPARTMENT OF NATURAL RESOURCES
Division of Geology and Land Survey

COVER:

This spring in McDonald County is one of the most scenic of the hundreds of springs throughout the southern half of Missouri. Photo by Jim Vandike.

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Missouri Water Quality Assessment

by
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PREFACE

MISSOURI STATE WATER PLAN TECHNICAL VOLUME SERIES

The Missouri Department of Natural Resources State Water Plan Technical Volume Series is part of a comprehensive state water resource plan. This portion is designed to provide basic scientific and background information on the water resources of the state. The information in these technical volumes will provide a firm foundation for addressing present and future water resource needs and issues. Each volume in the series deals with a specific water resource component.

Volume I

The ***Surface Water Resources of Missouri*** contains a basin-by-basin assessment of Missouri's surface water resources. It discusses the effects of climate, geology and other factors on the hydrologic characteristics of major lakes, streams and rivers. It also assesses surface-water availability and development in the state.

Volume II

The ***Groundwater Resources of Missouri*** presents information on the availability and natural quality of groundwater throughout the state. It focuses on Missouri's seven groundwater provinces and includes their geology, hydrogeology, areal extent, general water quality, and potential for contamination. Aquifer storage estimates are given for each aquifer and county. The report also reviews the different types of water-supply wells in use and how water well construction techniques vary between areas and aquifers.

Volume III

Missouri Water Quality Assessment focuses on the current quality of Missouri surface water and ground-water. The volume looks at chemical, bacteriological and radiological water-quality, and natural and man-induced water-quality changes.

Volume IV

The ***Water Use of Missouri*** describes how Missouri is presently using its surface-water and groundwater resources. The report covers private and public water supplies, industrial and agricultural water uses, and water use for electrical power production, navigation, recreation, fish and wildlife.

Volume V

Hydrologic Extremes in Missouri: Flood and Drought provides basic information about flood and drought specific to Missouri. A historical perspective is given, as well as information that can be used in planning for hydrologic extremes. It also describes concepts and defines terminology helpful in understanding flood and drought.

Volume VI

Water Resource Sharing - The Realities of Interstate Rivers presents Missouri's views concerning interstate rivers. Because of its location, Missouri can be greatly affected by activities and water policy in the upper basin states of the Missouri and Mississippi river basins. Missouri policy can also affect downstream states on the Mississippi, Arkansas and White rivers. Many serious issues affecting these rivers have less to do with their physical characteristics than with political, economic and social trends.

Volume VII

Missouri Water Law provides an overview of the laws that affect the protection and use of Missouri's water resources. It supplies reference information about existing doctrines, statutes and case law.

EXECUTIVE SUMMARY

Groundwater and surface water are used in many ways in Missouri, including recreation, fisheries, power generation, agricultural irrigation, transportation and drinking water. Maintaining good water quality is an environmental concern that is documented as early as 1907 in Missouri.

Water quality can be influenced by environmental factors such as precipitation, geology, topography, soil type, land use and water use. Groundwater quality varies regionally throughout the state, and is categorized and discussed according to each groundwater province. Seven groundwater provinces have been identified in Missouri using factors such as physiography, geology, hydrology, and vulnerability to contamination. These groundwater provinces are the Salem Plateau, St. Francois Mountains, Springfield Plateau, Osage Plains, Northeastern Missouri, Northwestern Missouri, and Southeastern Missouri (Bootheel), including Mississippi and Missouri rivers alluvial valleys.

The *Salem Plateau* groundwater province is located in south-central Missouri. Previously defined as the Ozark aquifer, groundwater here is characterized by water that is a calcium-magnesium bicarbonate type. Total dissolved solids (TDS) generally remain below the Missouri Safe Drinking Water Law recommended limit of 500 mg/l throughout the province except near the freshwater-salinewater interface at the northeastern and western edges of the province. TDS here can range from 1,000 mg/l to 10,000 mg/l, at which point the water becomes undesirable for most uses. Missouri's principal lead and zinc production area lies in this province and groundwater contamination in proximity to the mined areas can be quite common. Pesticides have been detected in wells and springs in this province, but at concentrations well below state standards.

The *St. Francois Mountains* groundwater province lies in southeastern Missouri, mirroring the St. Francois Mountains. Igneous, metamorphic, and sedimentary rocks all crop out in or near this province making it the most rugged topography in the state. Groundwater types vary, reflecting the mineral characteristics of the host rock formations. Concentrations of most constituents are well below drinking water standards, however there are some instances of high concentrations of lead, zinc, and sulfate in the vicinity of mining areas. Land use is primarily forest and thus nutrients and pesticides associated with other land uses are virtually nonexistent in this province.

The *Springfield Plateau* groundwater province is located in the southwestern part of the state. Its boundary mirrors the exposure of Mississippian rock formations at the surface. Water type in the Springfield Plateau aquifer is calcium bicarbonate, reflecting the chemistry of the limestones in which the water resides and travels. Most constituents are below state standards except where some influence from the freshwater-saltwater interface may be evident. Locally high sulfate concentrations can be found near mining areas of the Tri-State mining district near the Missouri-Kansas-Oklahoma borders. Agricultural land use results in

increased concentrations of nutrients and pesticides in springs and wells.

The *Osage Plains* groundwater province lies south of the Missouri River in western Missouri. Agriculture is prevalent in this region and pesticides and nutrients have been detected in wells. Pennsylvanian shales, sandstones, and limestones at the surface yield sodium-chloride type water that may be classified as moderately saline. Because of low yields and marginal quality this aquifer is not often utilized.

The *Northeast Missouri* groundwater province is located in the extreme northeastern part of the state. Glacial drift, Pennsylvanian sandstones and shales and Mississippian limestones provide the area with extensive plains and gently rolling hills. Water type varies with location and geology of the host formation. TDS can be quite high in water from the glacial drift and are generally lower in water from the other formations, but concentrations increase with depth. Agriculture is prevalent and excess nutrients and pesticides have been detected in shallow wells.

The *Northwest Missouri* groundwater province comprises the remainder of the state north of the Missouri River. Glacial drift and Pennsylvanian shales, limestones, and sandstones cover the province. Water type varies with differing host formations. TDS concentrations vary widely with areal distribution of the glacial drift. High levels of sulfate, chloride, iron, and manganese are prevalent in water from the glacial material. Pesticides and excess nutrients have been detected in shallow wells.

The *Southeast Missouri* groundwater province encompasses the area routinely referred to as Missouri's Bootheel. Alluvial deposits overlie older carbonate rocks. Water from the alluvium and the underlying Wilcox Group is generally low in TDS, and has better quality than deeper formations. With agriculture the predominant land use, contamination potential from agricultural chemicals is high. Missouri River alluvium has a total surface area of 2,000 square miles in Missouri. TDS concentrations vary widely and are related to length of residence time in and chemical composition of the aquifer. The alluvium is highly susceptible to contamination by agricultural chemicals.

Mississippi River alluvium covers approximately 800 square miles in Missouri. Widely variable TDS concentrations exist and contamination potential from agricultural chemicals is quite high. Twenty-seven percent of wells sampled during a study in 1988 had pesticide detections, although very few were at concentrations above maximum contaminant levels.

All of Missouri is drained either directly or indirectly by the Mississippi River and its tributaries. Major river systems contributing drainage to the Mississippi River are the Missouri, Arkansas, and the White rivers. Further delineations of these basins are 1) upper Mississippi River and its tributaries, 2) Missouri River tributaries north of the Missouri River, 3) Missouri River tributaries south of the Missouri River, 4) lower Mississippi River and its tributaries, 5) White River tributaries, and 6) Arkansas River tributaries.

Surface water supplies in the agricultural regions of northern, western, and extreme southeastern Missouri show the most pesticide detections.

Typical water type for the entire upper Mississippi River basin is calcium-magnesium bicarbonate. High nitrate plus nitrite as nitrogen concentrations in the basin may be the result of runoff containing fertilizer, and food processing industries in southern Iowa and northern Missouri, respectively. Streams and lakes near the urban area of St. Louis have been somewhat impacted by contaminants in urban runoff. Extensive channelization in the northern part of the basin has caused degradation to aquatic habitat. Agriculture is prevalent and agricultural chemicals have been detected at some time in most streams and lakes in the watershed.

The Missouri River and its tributaries north of the river drain the agricultural area of northern Missouri and agricultural chemicals are often detected in most surface water in the basin. Water type is predominantly calcium-magnesium bicarbonate. Extensive channelization has adversely impacted the quality and diversity of aquatic habitat. Kansas City is the major urban area within the watershed.

The Missouri River and its tributaries south of the river drain about 29.1 percent of the state. Along the western part of the basin, runoff and soil erosion rates are moderate to high, and most streams experience excessive sedimentation. Farther east, the tributaries in this basin traverse the physiographic province of the Ozark Plateaus and sediment content of the streams is less. Typical water type is a moderately-mineralized calcium-magnesium bicarbonate with some calcium bicarbonate water draining from the Springfield Plateau area. Most constituents are consistently below recommended state standards.

The Lower Mississippi River and its tributaries drain approximately 17 percent of Missouri. A complex series of man-made drainage ditches divert surface water east to the Mississippi River, thereby controlling flooding of the area. Though numerous rock types and ages appear at the surface throughout this basin, general water type for the entire watershed is calcium-magnesium bicarbonate. Land uses include agriculture, forest and urban.

Virtually the entire length of the White River in Missouri is impounded, forming three major reservoirs—Table Rock Lake, Lake Taneycomo, and Bull Shoals Lake. Interaction between groundwater and surface water is extensive thus surface water quality is highly influenced by groundwater quality in this region. Springfield is the major urban area within this basin.

Tributaries of the Arkansas River drain a small portion of southwestern Missouri. Mine wastes, industrial contaminants, and municipal wastewater discharges have historically had substantial impacts on the quality of surface water in this basin.

Long-term trend analysis of surface water quality of Missouri's larger rivers indicates a decrease in suspended solids in the Missouri and Mississippi rivers over the last 15 to 20 years, although no corresponding trend is detectable in interior rivers. Increasing levels of nitrate plus nitrite as nitrogen are evident in the Missouri, Mississippi, Elk, and Spring rivers. Higher sulfate concentrations in the Meramec, Spring, and Elk rivers are apparent. No trends in chloride, total phosphorus, dissolved oxygen, or trace metals have been detected.

INTRODUCTION

The 1900 census ranked Missouri fifth in population among the States of the Union. Rapid settlement made surface waters susceptable to contamination and increased the demand for water from deeper, more pure sources. Inquiries about artesian groundwater conditions in Missouri prompted a report titled *Underground Waters of Missouri, Their Geology and Utilization.* In his 1907 report, Edward M. Shepard voiced concerns about Missouri's water quality ...“Lakes, rivers, and springs have heretofore been the main dependence; but these are so generally becoming polluted by sewage, manufacturing wastes, and in other ways, that the problem of pure water is yearly more and more serious.” (Shepard, 1907). Although water pollution and other environmental regulations are in place today, public concern about the purity of groundwater and surface water remains high.

Missouri Water Quality Assessment is intended to provide a general description of the state's current surface water and groundwater quality. Concentrations of chemical, bacteriological, and radiological constituents vary in different areas of the state as a result of influence by numerous environmental factors.

The Missouri, the Mississippi, and the Arkansas-White River basins provide drainage of surface water for the state (figure 1). These major river basins are the basis for further delineation of drainage, and are used later in this publication to describe regional surface water quality. Groundwater quality varies regionally throughout the state, and is categorized and discussed according to groundwater province. Seven groundwater provinces have been identified using factors such as physiography, geology, hydrology, and vulnerability to contamination. These provinces are the **Salem Plateau, St. Francois Mountains, Springfield Plateau, Osage Plains, Northeastern Missouri, Northwestern Missouri**, and **Southeastern Missouri (Bootheel)**, including Mississippi and Missouri River alluvial valleys (figure 2).

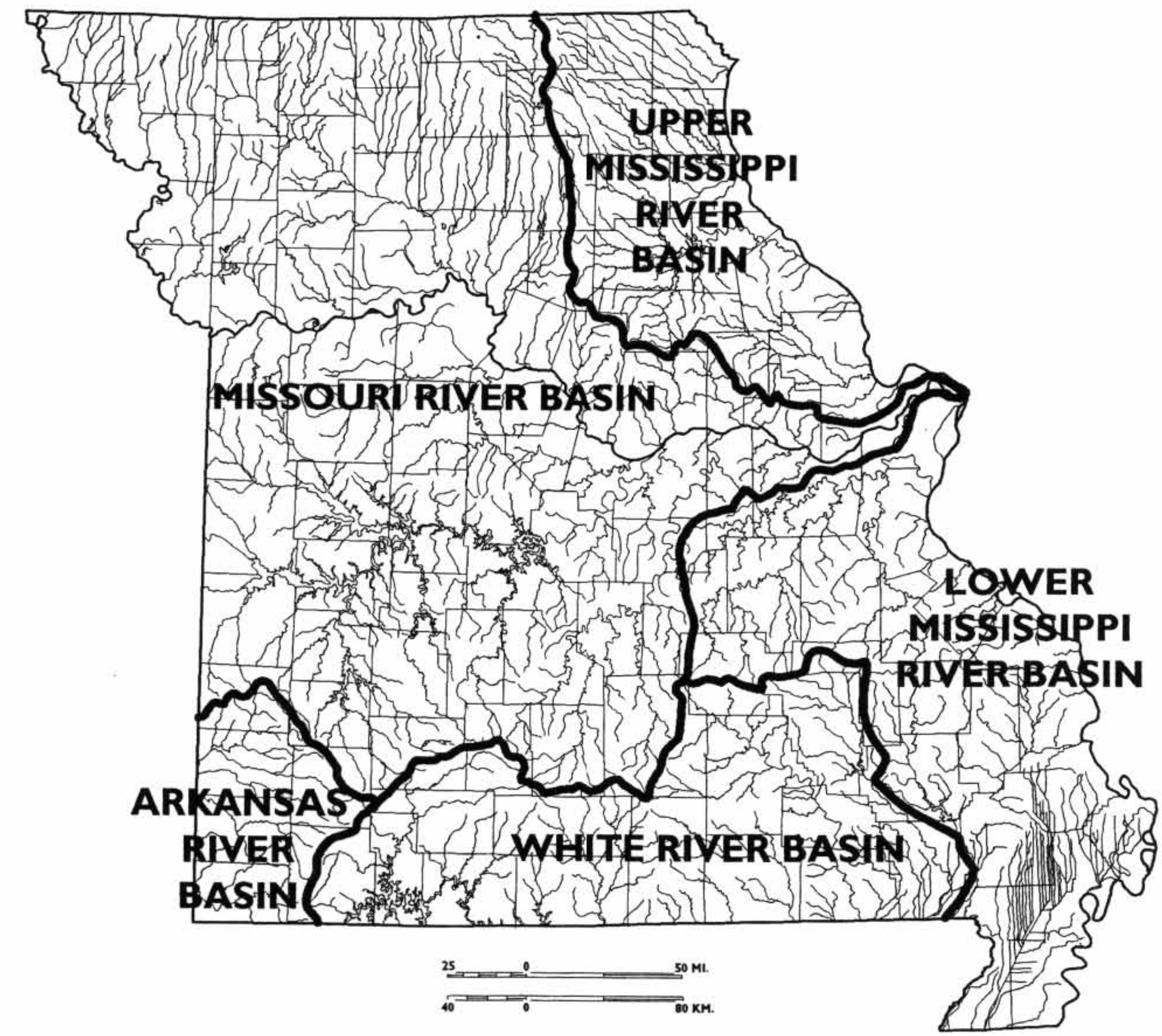

Figure 1. Major drainage basins in Missouri.

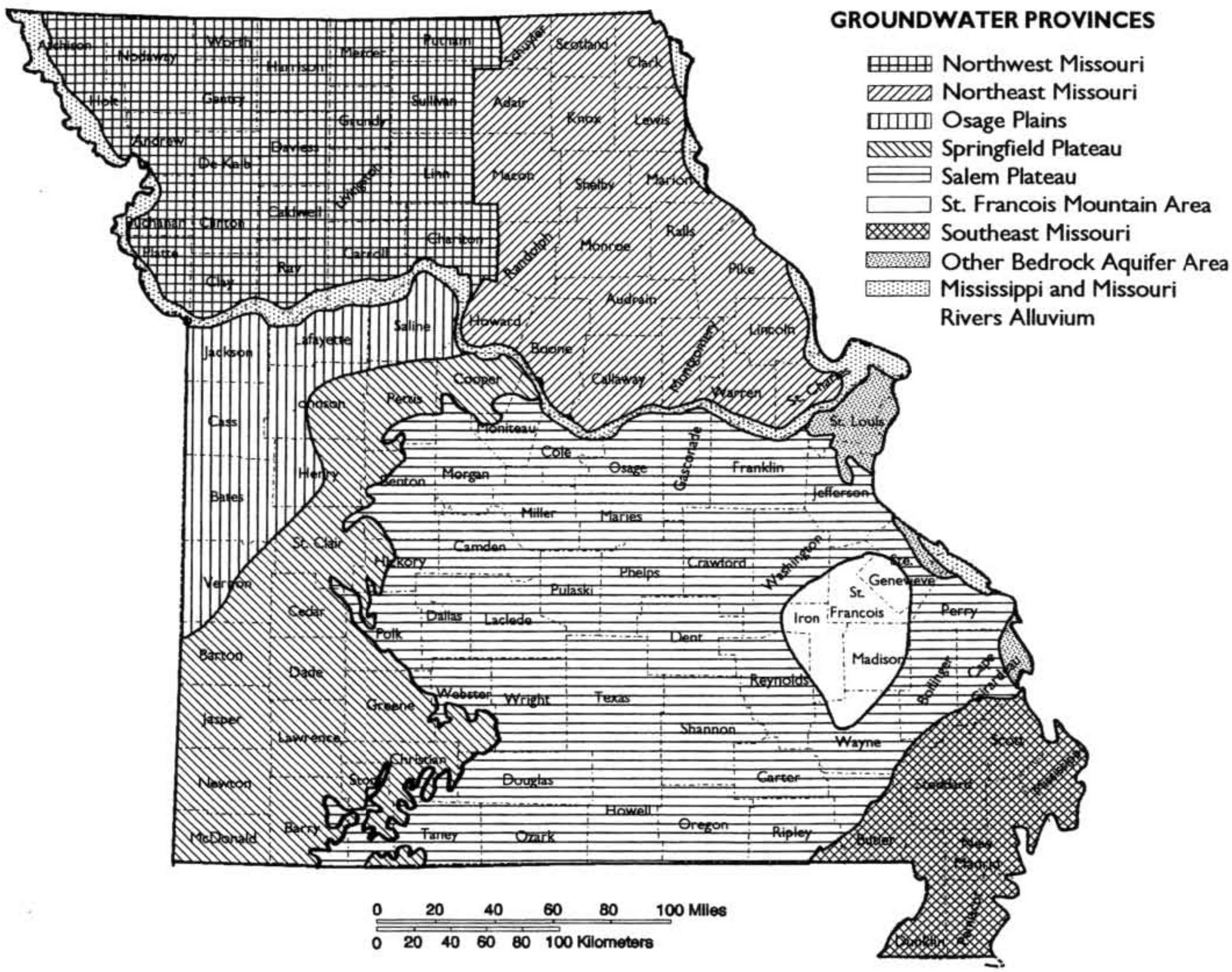

Figure 2. Groundwater provinces of Missouri.

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LOCATION AND CLIMATE

Missouri is located in the Midwestern United States. It is bordered on the north by Iowa, on the west by Nebraska, Kansas, and Oklahoma, on the south by Arkansas, and on the east by Tennessee, Kentucky, and Illinois. The state encompasses approximately 68,989 square miles and is divided into 114 counties, not including the city of St. Louis, which is considered a separate entity (figure 3).

Missouri's climate is moderate with temperatures and precipitation that vary regionally. The total annual precipitation for extreme northwestern Missouri is approximately 35 inches, while counties along the southeastern border average approximately 47 inches per year (figure 4). Seasonal trends indicate that the smallest amount of precipitation occurs in the fall and winter months, and the largest during the spring (figure 5). Rainfall runoff averages 6 inches per year in the northwestern part of the state and up to 20 inches per year in the extreme southeast (figure 6). Total annual evaporation of precipitation varies from 60 inches in the western areas to 50 inches on the eastern border (Miller and Vandike, 1996).

Figure 3. Missouri and surrounding states.

Figure 4. Average annual precipitation for Missouri.

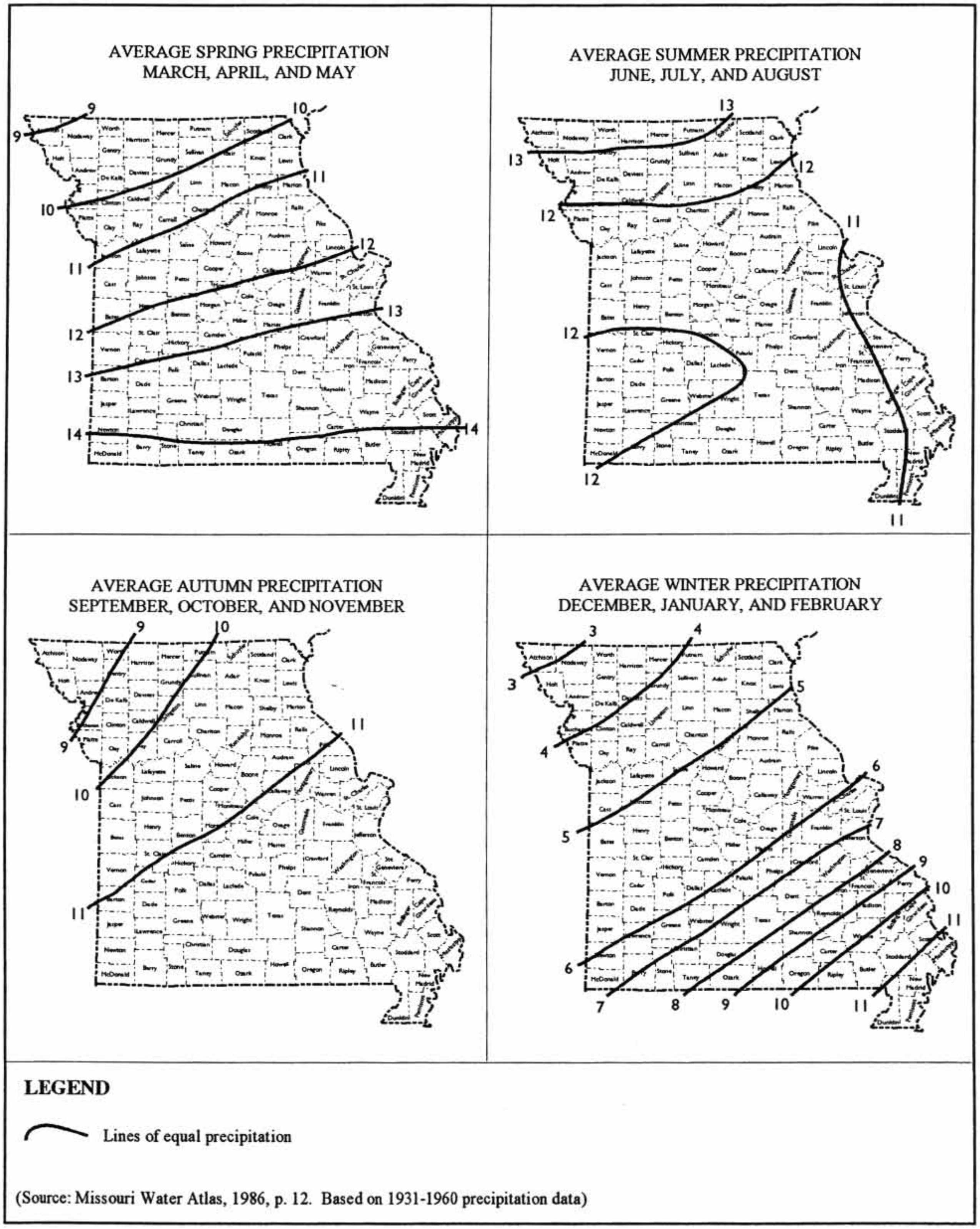


Figure 5. Average seasonal precipitation.

Figure 6. Average annual runoff for Missouri

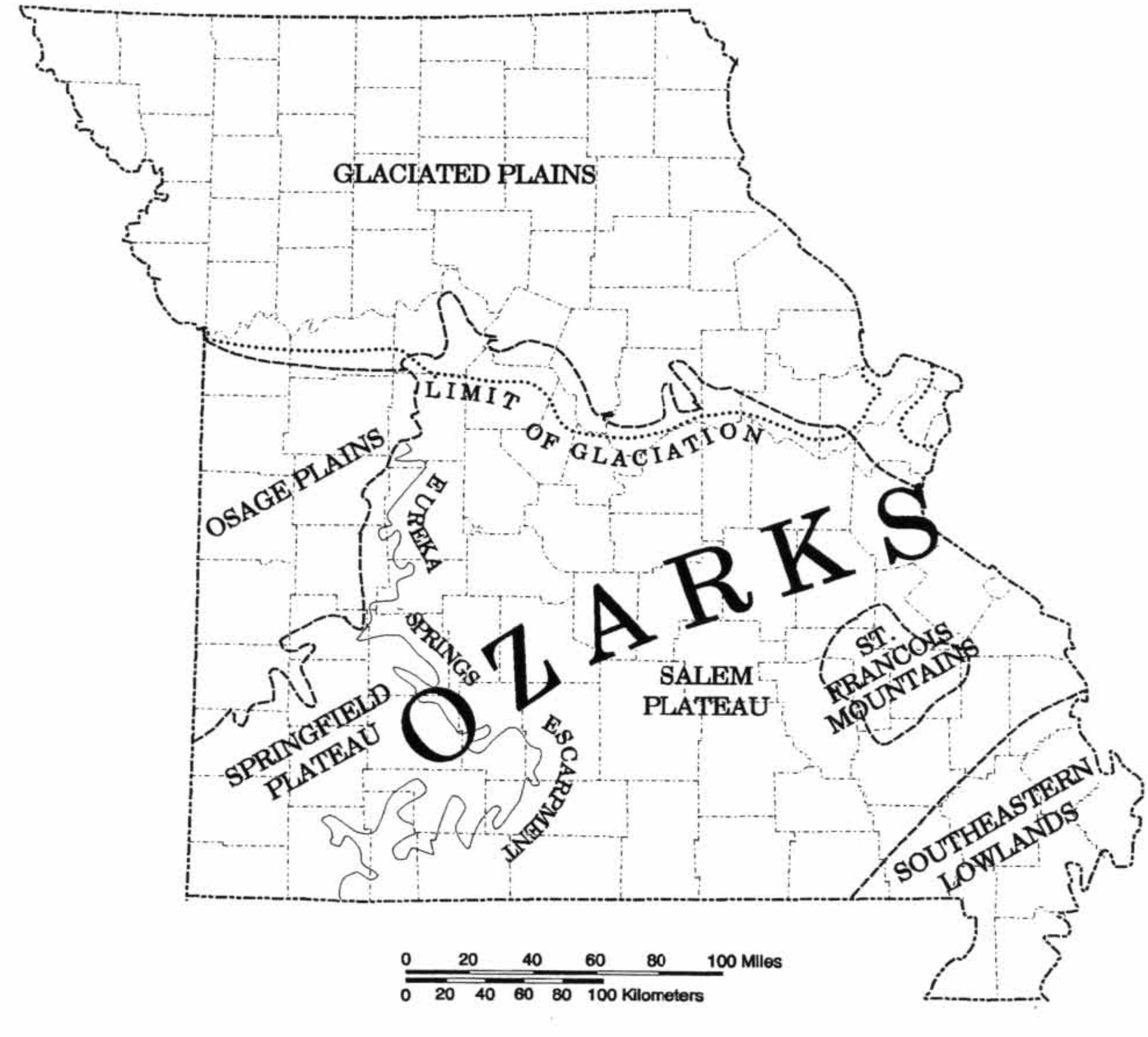


Figure 7. Physiographic provinces.

PHYSIOGRAPHY

Portions of three physiographic provinces are represented in Missouri (figure 7). The **Central Lowland** province covers the northern and some of the western parts of the state. Subdivisions of this province include the *Glaciated Plains* and the *Osage Plains*.

The *Glaciated Plains*, which are the area north of the southern limit of glaciation, are characterized by plains of glacial till (clay, silt, sand, and gravel) that are continually becoming more dissected by surface drainage. The unglaciated Osage Plains of west-central Missouri have more gentle topography than northern Missouri because more competent Pennsylvanian-age shales, limestones, and sandstones underlie the area.

Most of southern Missouri is included in the **Interior Highlands** province, *Ozark Plateau* subprovince. The *Ozark Plateau* is further divided into the *Springfield Plateau, Salem Plateau*, and the *St. Francois Mountains*. The topography in this region developed from a major uplift centered in the St. Francois Mountains in southeastern Missouri. Precambrian-age rocks crop out at the center of the domal uplift and sequentially younger rocks surround the center and dip away from it with steeper dips occurring to the northeast, east, and southeast.

The Missouri "Bootheel," or southeastern lowlands area, is included in the *Mississippi Alluvial* Plain subprovince of the **Coastal Plain** province. Quaternary alluvium comprised of sand, gravel, silt, and clay deposited by the Mississippi, Ohio, and St. Francis rivers typically covers the Bootheel area. The exception in topographic relief in the Bootheel area is supplied by Crowleys Ridge, Hickory Ridge and the Benton Hills. These erosional remnants of previous plains rise as much as 250 feet above the adjacent alluvial plain. They are Tertiary to Paleozoic in age and parallel the northwestern edge of the province (after DGLS, 1967). Figure 8 shows the general bedrock geology for the state.

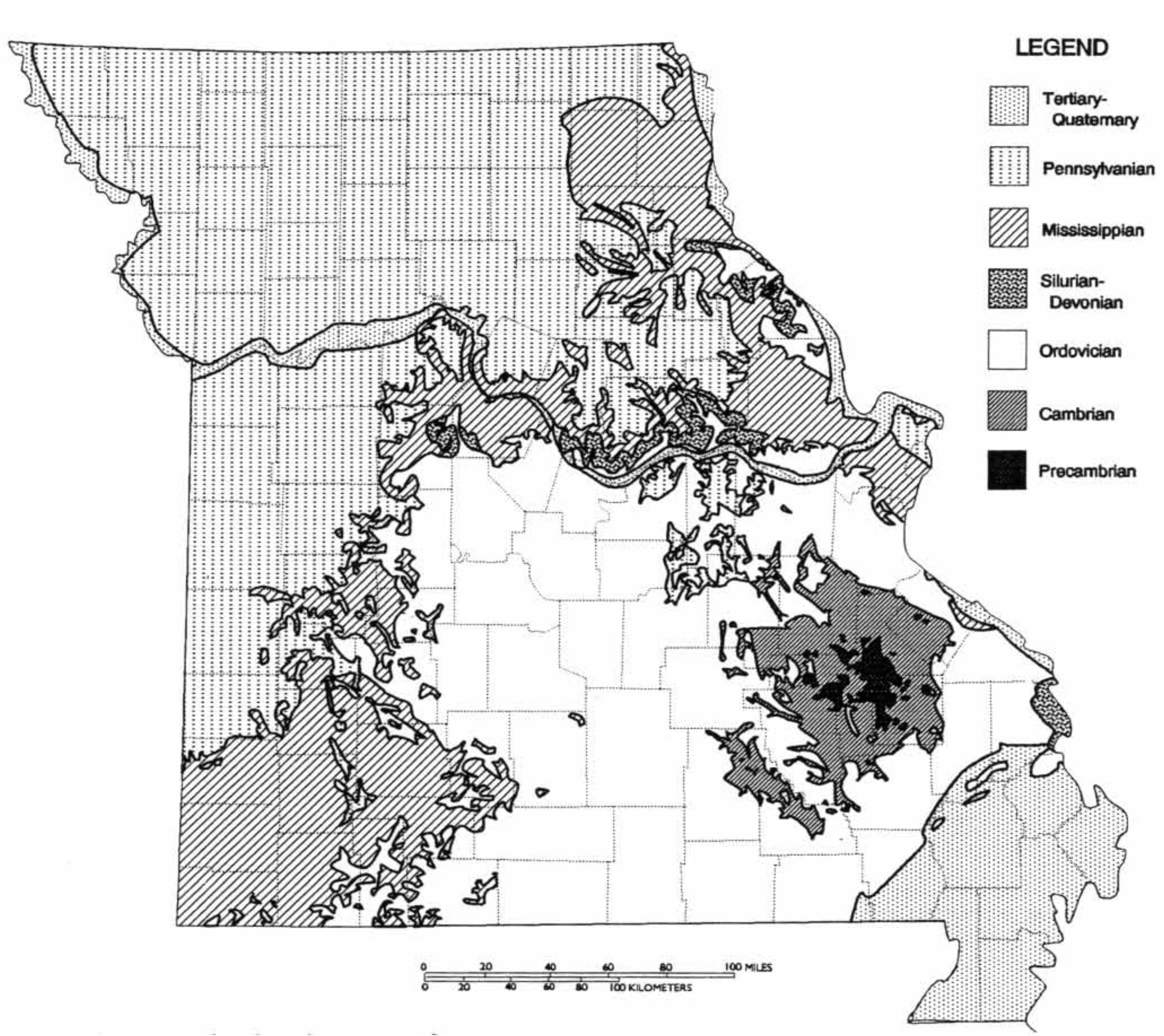


Figure 8. Generalized geologic map of Missouri.

GENERAL GROUNDWATER QUALITY

Approximately 40 percent of Missouri's population depends upon groundwater as their source of drinking water. Due to this important use, it is desirable to characterize the natural quality of the groundwater. In order to accomplish this, some limits of organic, inorganic, bacteriological, and radiological constituents must be used for comparison to ambient levels. Missouri Clean Water Law (RSMo 644.006) includes criteria pertaining to groundwater in its Water Quality Standards (10 CSR 20-7) (Appendix A). These groundwater standards parallel the Missouri Safe Drinking Water Standards, which will be used for comparison of constituents to ambient conditions in most situations. The Missouri Safe Drinking Water Law (RSMo 640.100-640.140) designates maximum contaminant levels for various constituents for public drinking water systems. These maximum levels are detailed in tables 1-5. Some constituents listed in these tables occur naturally and some only as a result of man's intervention in the environment. However, these maximum contaminant levels provide a good basis for determination of the potability and effective use of water and will be used as such in this report. The terms *excess* and *excessive*, when used as modifiers for constituent concentrations, mean values that are well above standard, typical, or ambient concentrations.

Groundwater quality can be influenced by several environmental factors—precipitation, geology, topography, soil type and its thickness, land use, and even water use; all of these may have an affect on the quality of groundwater. Some of these factors, such as precipitation, contribute to short-term, short-lived changes while others, like water use, may affect groundwater quality over a long period of time.

Precipitation, topography, and soil type and its thickness can contribute to changes in the quality of shallow groundwater. For example, precipitation funneled directly to the subsurface via sinkholes, or through very thin, permeable soils, may contribute surface contaminants to the shallow aquifer that would have been filtered out had the precipitation passed through thicker, less permeable soils. Land use practices, such as pesticide application in agricultural areas, also may contribute contaminants to the shallow groundwater system. Water use practices such as large and lengthy groundwater withdrawals can, in some instances, change the direction of groundwater flow, which might allow contaminant migration rates and directions to change.

The geological makeup of the subsurface formations where water resides is an important factor in determining types of groundwater. Soil and rock formations contribute minerals and other constituents to the groundwater as it passes through or resides in the formation. Table 6 lists the source and significance of several constituents used in defining groundwater quality. Because of the influence of geology on water quality, a brief discussion of geology will be included in each groundwater province section. Figure 9 illustrates the general geology and stratigraphic position of the geologic formations that comprise each groundwater province.

Other factors that determine water type are the amount of carbon dioxide present in

INORGANIC CONTAMINANTS

CONTAMINANT	MAX. CONTAMINANT LEVEL
Antimony	0.006 mg/l
Arsenic	0.05 mg/l
Asbestos	7 million fibers/l
Barium	2 mg/l
Beryllium	0.004 mg/l
Cadmium	0.005 mg/l
Chromium	0.1 mg/l
Copper	Copper Action Level*
Cyanide	0.2 mg/l
Fluoride	4 mg/l
Lead	Lead Action Level **
Mercury	0.002 mg/l
Nickel	0.1 mg/l
Nitrate	10 mg/l (as nitrogen)
Nitrite	1 mg/l (as nitrogen)
Total Nitrate & Nitrite	10 mg/l (as nitrogen)
Selenium	0.05 mg/l
Thallium	0.002 mg/l
Modified from Missouri Safe Drinking Water Law (Section 640.100 - 640.140, Revised Statutes of MO)	

* Copper Action Level is exceeded if concentration in more than 10% of samples collected during any monitoring period is greater than 1.3 mg/l

** Lead Action Level is exceeded if concentration in more than 10% of samples collected during any monitoring period is greater than 0.015 mg/l

Table 1. Maximum contaminant levels for public drinking water systems

VOLATILE ORGANIC CHEMICALS

CONTAMINANT	MAXIMUM CONTAMINANT LEVELS (MG/L)
Benzene	0.005
Carbon Tetrachloride	0.005
1,2-dichloroethane	0.005
1,1-dichloroethylene	0.007
Carbon tetrachloride	0.005
1,2 - dichloroethane	0.005
1,1 - dichloroethylene	0.007
para-dichlorobenzene	0.075
1,1,1-trichloroethane	0.2
Trichloroethylene	0.005
Vinyl chloride	0.002
cis-1,2-dichloroethylene	0.07
Dichloromethane	0.0005
1,2-dichloropropane	0.05
Ethylbenzene	0.7
Monochlorobenzene	0.1
0-dichlorobenzene	0.6
Styrene	0.1
Tetrachloroethylene	0.005
Toluene	1
1,2,4-Trichlorobenzene	0.07
1,1,2-Trichloroethane	0.005
trans-1,2-dichloroethylene	0.1
Xylenes (total)	10.0
Modified from Missouri Safe Drinking Water Law (Section 640.100 - 640.140, Revised Statutes of MO)	

Table 2. Maximum contaminant levels for public drinking water systems.

SYNTHETIC ORGANIC CHEMICALS

CONTAMINANT	MAXIMUM CONTAMINANT LEVEL (MG/L)
Alachlor	0.002
Atrazine	0.003
Benzo(a)pyrene	0.0002
Carbofuran	0.04
Chlordane	0.002
Dalapon	0.2
Di(2-ethylhexyl)adipate	0.4
Dibromochloropropane(DBCD)	0.0002
Di(2-ethylhexyl)phthlate	0.006
Dinoseb	0.007
Diquat	0.02
Endothall	0.1
Endrin	0.0002
2,4-E	0.07
Ethylene dibromide (EDB)	0.00005
Glyphosate	0.7
Heptachlor	0.0004
Heptachlor epoxide	0.0002
Hexachlorobenzene	0.001
Hexachlorocyclopentadiene	0.05
Lindane	0.0002
Methoxychlor	0.04
Modified from Missouri Safe Drinking Water Law (Section 640.100 - 640.140, Revised Statutes of MO)	

Table 3. Maximum contaminant levels for public drinking water systems

Table 3 (continued) Maximum contaminant levels for public drinking water systems.

SYNTHETIC ORGANIC CHEMICALS

CONTAMINANT	MAXIMUM CONTAMINANT LEVEL (MG/L)
Oxamyl (vydate)	0.2
Picloram	0.5
Polychlorinated biphenyls (PCBs)	0.0005
Pentachlorophenol	0.001
Simazine	0.004
Toxaphene	0.003
2,3,7,8-TCDD (Dioxin)	0.00000003
2,4,5-TP (Silvex)	0.05
Modified from Missouri Safe Drinking Water Law (Section 640.100 - 640.140, Revised Statutes of MO)	

CONTAMINANT	**LEVEL**
Aluminum	0.05 - 0.2 mg/l
Chloride	250 mg/l
Color	15 color units
Copper	1.0 mg/l
Corrosivity	Noncorrosive
Fluoride	2.0 mg/l
Foaming Agents	0.5 mg/l
Iron	0.3 mg/l
Manganese	0.05 mg/l
Odor	3 Threshold Odor #
pH	6.5 - 8.5
Silver	0.1 mg/l
Sulfate	250 mg/l
Total Dissolved Solids (TDS)	500 mg/l
Zinc	5 mg/l
*Recommend Secondary Maximum Contaminant Levels are based on taste and odor rather than health risks	
Modified from Missouri Safe Drinking Water Law (Section 640.100 - 640.140, Revised Statutes of MO)	

Table 4. Recommended secondary maximum contaminant levels for public water supply systems*

RADIONUCLIDE

CONTAMINANT	MAXIMUM CONTAMINANT LEVEL (picocurie/l)
Radium ^{226} + Radium ^{228}	5.0
Gross alpha including Radium^{226} but excluding radon and uranium	15.0
Gross beta	50.0
Modified from Missouri Safe Drinking Water Law (Section 640.100 - 640.140, Revised Statutes of MO)	

Table 5. Maximum contaminant levels for public drinking water systems.

the water as it reaches the water table, the order in which water contacts the formations, and the residence time in each formation (Imes & Davis 1991). Examples of water types are bicarbonates of calcium, magnesium, and sodium; chlorides of calcium, magnesium, and sodium; sulfates of calcium, magnesium, and sodium, and various combinations of the same.

Bacterial contamination is a concern when dealing with drinking water. State regulations require each public water supply to routinely perform tests for coliform bacteria, a type of bacteria, which, when present, is used as an indicator for possible contamination by other more harmful species of bacteria. While coliform bacteria is commonly found at or near the surface in soil and other surface materials and water, it is rarely found to exist naturally in Missouri groundwater. Occurrences of this bacteria in groundwater usually indicate the introduction of contaminants from the surface either through natural karst features such as sinkholes and losing streams, improper well construction or maintenance, or inadequately functioning septic systems.

The presence of coliform bacteria in groundwater is generally short-lived and can be eliminated by chlorination or maintenance on the water-supply system. A statewide survey of 861 private water-supply wells, conducted by the Missouri Department of Health in 1994, showed that approximately 57 percent of those wells were contaminated with coliform bacteria. Approximately 23 percent had E. coli bacteria, a specific member of the coliform group that is closely associated with human fecal wastes. Improper well construction is thought to be the cause of such numerous occurrences of bacteria in private wells. Though bacterial contamination is generally a condition of private wells utilizing shallow groundwater, exceeding the Missouri Safe Drinking Water MCL for coliform bacteria in public water-supply wells is documented. From October 1992 to September 1993, approximately 8 percent of all public water supplies using groundwater in Missouri had MCL violations for bacteria. By the end of September 1995, the yearly occurrence of MCL violations for bacteria in public water supplies using groundwater had decreased to 6 percent (Eichholz, pers. comm, 1997).

Another concern is the presence of radioactive nuclides, or radionuclides in groundwater. Radioactive decay of certain unstable elements produces radiation called alpha, beta, and gamma radiation. The human body is susceptible to damage if exposed to massive quantities of radiation, or low-level quantities over an extended period, from these radioactive elements. Some consequences of exposure are leukemia, birth defects, mental retardation, and tumors (Driscoll, 1986). While use

CONSTITUENT	SOURCE	SIGNIFICANCE
Silica (SiO_2)	Dissolved from nearly all rocks and soils. High concentrations, as much as 100 mg/l generally occur in highly alkaline waters.	Calcium or magnesium silicate forms hard scale in piping. Does not contribute to total hardness.
Iron (Fe)	Dissolved from nearly all rock and soils. May also be derived from iron pipes, pumps and other equipment.	More than 0.3 mg/l stains laundry and utensils reddish brown. Objectionable for food or textile processing, beverages, ice manufacture, and brewing. Large amounts cause unpleasant taste and enhance growth of iron bacteria.
Manganese (Mn)	Dissolved from some rocks and soils. Not as common as iron. Large quantities often associated with high iron content.	Same objectionable features as iron. Causes dark brown or black stain.
Calcium (Ca) and Magnesium (Mg)	Dissolved from nearly all rocks and soils, especially limestone, dolomite, and gypsum. Ca and Mg are found in large quantities in some brines	Cause most of the hardness and scale-forming properties of water, consumes soap. Water low in Ca and Mg is desired in electroplating, tanning, and dyeing, and in textile manufacturing.
Sodium (Na) and Potassium (K)	Dissolved from nearly all rocks and soils.	Large amounts of sodium chloride give a salty taste. Groundwater generally contains 10-100 mg/l Na. Sodium salts may cause foaming in steam boilers and limit the use of water for irrigation. Consumption of high-sodium content water may contribute to high blood pressure.
Bicarbonate (HCO_3) and Carbonate (CO_3)	Action of carbon dioxide in water on carbonate rocks such as limestone and dolomite.	HCO_3 and CO_3 produce alkalinity. Combined with calcium and magnesium they cause carbonate hardness.
Sulfate (SO_4)	Dissolved from rocks and soils containing gypsum, iron sulfides, and other sulfur compounds. Commonly present in mine waters and some industrial wastes.	In large amounts, sulfate in combination with other ions gives a bitter taste. Sulfate in water containing calcium forms hard scale in steam boilers.
Chloride (CL)	Dissolved from rocks and soils. Present in sewage and found in large amounts in brines, sea water, and industrial wastes.	Large amounts in combination with sodium gives salty taste. Large quantities increase the corrosiveness of water. Groundwater in limestone averages 6 mg/l, while granite averages 12-13 mg/l.
Fluoride (F)	Dissolved in small quantities from most rocks and soils. Added to many municipal water supplies by fluoridation.	In drinking water reduces the incidence of tooth decay. May also cause mottling of the teeth in certain situations. Maximum recommended concentration varies with annual average of maximum daily air temperatures.
Nitrate (NO_3)	Decaying organic matter, legume plants, sewage, nitrate fertilizers and nitrates in soils.	High content serves as indicator that aquifer should be tested for harmful bacteria that may accompany contamination. Particularly troublesome in karstic regions where water movement through solution openings is rapid and allows for little dilution.
Dissolved solids	Chiefly mineral constituents dissolved from rocks and soils	Waters containing more than 1,000 mg/l are unsuitable for many purposes.
Hardness as $CaCO_3$	Nearly all hardness is due to calcium and magnesium. Metallic cations other than the alkali metals also cause hardness.	Consumes soap before lather will form. Hard water forms scale on water heaters, pipes, and boilers. Carbonate hardness includes bicarbonate and carbonate equivalents. Categories of water hardness are; up to 50 mg/l - soft, 50 - 150 mg/l - moderately hard, 150 - 200 mg/l - hard, more than 200 mg/l - very hard.
Specific Conductance	Mineral content of the water.	Indicates degree of mineralization. Specific conductance is a measure of the capacity of the water to conduct an electric current. It varies with the concentrations and degree of ionization of the constituents, and with temperature.
Hydrogen -ion concentration (pH)	pH of groundwater results from balance between carbon dioxide from the atmosphere and biological activity and dissolved carbonates and bicarbonates from carbonate rocks.	pH is the hydrogen ion content of water. A pH of 7.0 indicates neutrality, lower values denote increasing acidity, and higher values denote increasing alkalinity. Water with lower pH is generally more corrosive.
Color	Yellow to brown color is usually caused by organic matter. Color can also result from industrial wastes and sewage.	Water from domestic and some industrial uses should be colorless. Color in water is objectionable in food and beverage processing and many manufacturing processes.
Temperature	Climatic conditions, use of water as a cooling agent, industrial pollution.	Temperature affects usefulness of water for many purposes.
Suspended Sediment	Erosion of land and stream channels. Quantity and particle size gradation is affected by many factors such as precipitation, runoff, flow characteristics, topography, soil types, agricultural practices, and industrial and mining activities.	Sediment must generally be removed before water is used by industry or municipalities. Sediment deposits reduce the storage capacity of reservoirs and lakes.

Table 6. Chemical constituents of groundwater (modified from Feder et al., 1969).

SYSTEM	SERIES	GROUP	GEOLOGIC UNIT	HYDROGEOLOGIC UNIT
Quaternary	Holocene		Alluvium	Missouri and Mississippi rivers and in Mississippi embayment, 500-2000 gpm. Yields are less along smaller rivers.
	Pleistocene		Loess, till, and other drift, sand and gravel	Drift and till typically yield 0-5 gpm. Drift-filled preglacial valleys typically yield 50-500 gpm.
Tertiary	(undifferentiated)			Wilcox Group (Mississippi embayment only), 50-400 gpm.
Cretaceous	(undifferentiated)			McNairy Formation (Mississippi embayment only), 200-500 gpm
Pennsylvanian	(undifferentiated)			Northern and west-central Missouri, 1-20 gpm, regionally forms a confining layer.
Mississippian	Chesterian		(undifferentiated)	Springfield Plateau aquifer Southwest, central, and eastern Missouri, 5-30 gpm.
	Meramecian		(undifferentiated)	
	Osagean		Keokuk Limestone Burlington Limestone Grand Falls Formation Reeds Spring Formation Pierson Formation	
	Kinderhookian	Chouteau	Northview Formation Sedalia Formation Compton Formation	Ozark confining unit
			Hannibal Formation	
Devonian	(undifferentiated)			
Silurian	(undifferentiated)			
Ordovician	Cincinnatian		Orchard Creek Shale Thebes Sandstone Maquoketa Shale Cape Limestone	
	Champlainian		Kimmswick Formation Decorah Formation Plattin Formation Joachim Dolomite Dutchtown Formation St. Peter Sandstone Everton Formation	Ozark aquifer (upper) Yield is greatest from St. Peter Sandstone. Yields of 5 to 50 gpm are possible.
	Canadian		Smithville Formation Powell Dolomite Cotter Dolomite Jefferson City Dolomite Roubidoux Formation Gasconade Dolomite Gunter Sandstone Member	Ozark aquifer (lower) Yields vary greatly with location and well depth. In Salem Plateau, yields are typically 50-500 gpm. In Springfield Plateau and central Missouri, yields are typically 500 to 1200 gpm.
Cambrian	Upper Cambrian		Eminence Dolomite Potosi Dolomite	
		Elvins	Derby-Doerun Dolomite Davis Formation	St. Francois confining unit.
			Bonneterre Formation Lamotte Sandstone	St. Francios aquifer. Yields of 10 to 100 gpm are possible.
Precambrian	(undifferentiated)		Igneous, metasediments, and other metamorphic rock.	Not a significant aquifer

[The stratigraphic nomenclature used in this report is that of the Missouri Department of Natural Resources, Division of Geology and Land Survey modified after Koenig (1961.]

Figure 9. General stratigraphy of Missouri.

of atomoic energy may increase average exposure of groundwater to radioactive elements in certain locations, natural occurrence has been documented where radionuclides exist in groundwater in Missouri. Long residence time underground allows groundwater to accumulate elements from its host rock, and thus a potential for radioactive contamination exists.

Public drinking water supplies are required to test for the presence of radionuclides every four years. Maximum contaminant levels of gross alpha, gross beta, and radium^{226} plus radium^{228} have been defined and are shown in table 5. Analyses from samples submitted between November 1993 and September 1996 show that 108 public water supplies had gross alpha levels above the maximum contaminant level of 5.0 picocuries per liter (pCi/l) as listed in table 7. Of those supplies, 14 also had concentrations of radium^{226} plus radium^{228} above the maximum contaminant level of 5.0 pCi/l (Missouri Dept. of Natural Resources, 1996). Figure 10 and tables 7 and 8 show the locations and names of those supplies.

Table 7. Public water supplies with Gross Alpha >5.0 pCi/l (1993-1996) (DNR, 1996). Continued next page.

COUNTY	PUBLIC WATER SUPPLY
Barry	Chain of Lakes Subdivision
Barry	Purdy
Barton	Golden City
Barton	Mindenmines
Boone	Ashland
Boone	Bon-Gor Lake Estates Sub.
Boone	Boone Co. PWSD #1
Boone	Boone Co. PWSD #4
Boone	Boone Co. Consolidated PWSD #1
Boone	Boone Co. PWSD #7
Boone	Boone Co. PWSD #9
Boone	Boone Co. PWSD #2
Boone	Mobile Village MHP
Boone	Rocheport
Boone	Stonegate MHP
Boone	Woodhaven Learning Center
Callaway	Callaway Co. PWSD #2
Callaway	Callaway Co. PWSD #1
Callaway	Jefferson City - North
Callaway	New Christian Life Fellowship

Table 7 continued...

COUNTY	PUBLIC WATER SUPPLY
Camden	Osage Water Company
Cape Girardeau	North Hills Estates Sub.
Cedar	El Dorado Springs
Cedar	Stockton
Cole	Propst MHP
Douglas	Ava
Franklin	Kobers MHP
Franklin	Lake Serene Subdivision
Franklin	Orchard Estates Subdivision
Franklin	St. Albans Partners
Franklin	St. Albans Water & Sewer
Greene	Ash Grove
Greene	Pembrook Subdivision
Henry	Urich
Howell	Mountain View
Iron	The Baptist Nursing Home
Jasper	Asbury
Jasper	Carl Junction
Jefferson	Blue Fountain MHP
Jefferson	Jefferson Co. PWSD #6
Jefferson	Meadow View Acres MHP
Jefferson	Pine Ford Village MHP
Jefferson	Riverside Subdivision
Jefferson	Sunrise Lakes Subdivision
Jefferson	Valle Acres MHP
Jefferson	Woodhurst MHP
Johnson	Chilhowee
Johnson	Forest Trails Estates MHP
Johnson	Johnson Co. PWSD #2

Table 7 continued...

COUNTY	PUBLIC WATER SUPPLY
Lincoln	Charwood Estates
Lincoln	Hawk Point
Lincoln	Lakeview
Lincoln	Lincoln Co. PWSD #1
Lincoln	Lindemann MHP
Lincoln	Silex Nursing Home
Lincoln	Silex
Lincoln	Troy
McDonald	Lanagan
McDonald	Noel
McDonald	Pineville
McDonald	Southwest City
Mississippi	Wyatt
Montgomery	Bellflower
New Madrid	Portageville
New Madrid	Risco
Newton	Fairview
Newton	Loma Linda Estates Subdivision
Newton	Park Place MHP
Perry	Altenburg
Perry	Perry County PWSD #1
Pettis	LaMonte
Pike	Clarksville
St. Charles	Big Country Lake Estates
St. Charles	Country Estates Subdivision
St. Charles	St. Judes Subdivision
St. Charles	Weldon Spring Heights Village
St. Francois	Bonne Terre
St. Francois	Farmington
St. Francois	L&J Residential Care

Table 7 continued...

COUNTY	PUBLIC WATER SUPPLY
St. Francois	Leadwood
St. Francois	Park Hills
St. Francois	Pilot Knob
St. Francois	St. Francois Co.PWSD #1
St. Francois	St. Francois Co. PWSD #2
St. Francois	Terre Du Lac Subdivision
St. Francois	Wyckliff Meadows Subdivision
St. Louis	MO Eastern Correctional Center
Stoddard	Dexter
Stoddard	Essex
Stoddard	Mingo CCC
Stone	Branson West
Stone	Crane
Stone	Golden Acres Subdivision
Stone	Kimberling City Water Co.
Taney	Branson
Taney	Moore Bend Subdivision
Taney	Ozark Park Estates MHP
Taney	Plantation Hill Nursing
Taney	Tri-State utility Co.
Taney	Valley View Village South
Taney	Valley View Heights Sub.
Vernon	Bronaugh
Vernon	Walker
Warren	Cedar Grove Village Sub
Warren	Incline Village Subdivision
Warren	Lake Sherwood Subdivision
Warren	Truesdale
Wayne	Ridgetop Waterworks Corp.

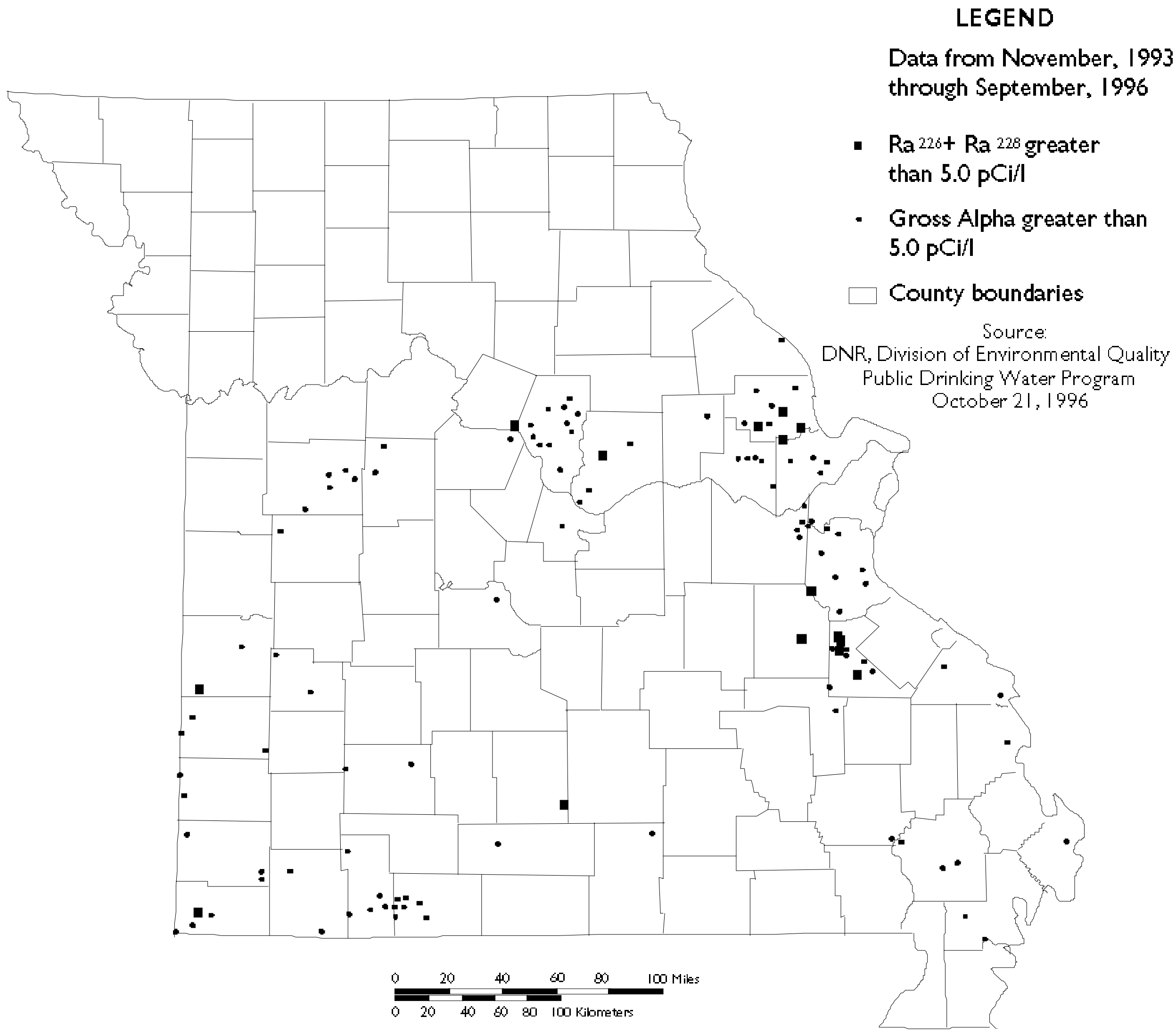


Figure 10. Approximate locations of public water supply wells with radionuclide detection over 5.0 Picocuries per liter.

COUNTY	**PUBLIC WATER SUPPLY**
Boone	Rocheport
Callaway	New Christian Life Fellowship
Jefferson	Pine Ford Village MHP
Lincoln	Lincoln County PWSD #1
Lincoln	Lindemann MHP
McDonald	Lanagan
St. Charles	Country Estates Subdivision
St. Francois	Bonne Terre
St. Francois	Leadwood
St. Francois	St. Francois County PWSD #1
St. Francois	Wyckliff Meadows Subdivision
Vernon	Bronaugh
Washington	Potosi
Wright	Mountain Grove

Table 8. Public Water Supplies with $Radium^{226}$ + $Radium^{228}$ >5.0 pCi/l.

Figure 11. Salem Plateau groundwater province.

SALEM PLATEAU

LOCATION AND GEOLOGY

The Salem Plateau groundwater province includes all or part of 47 counties in Missouri (figure 11). For simplification, future references to both the Salem Plateau groundwater province and Salem Plateau province will refer to the boundary of the groundwater province. Most of the area south of the Missouri River is included in this province. Sedimentary rock formations outcropping at the surface range in age from Cambrian to Recent including dolomites, limestones, and shales. However, many of the formations that comprise this groundwater province are present only in the subsurface. Although the province is named after its physiographic location, the rocks comprising the aquifer have been previously defined as the Ozark aquifer and the overlying Ozark confining unit (USGS, 1994).

The formations included in the Salem Plateau groundwater province are, in descending order, loess and residuum, undifferentiated Pennsylvanian formations, undifferentiated Mississippian formations, the Ozark aquifer comprised of St. Peter Sandstone, Everton Formation, Smithville Dolomite, Powell Dolomite, Cotter Dolomite, Jefferson City Dolomite, Roubidoux Formation, Upper Gasconade Dolomite, Lower Gasconade Dolomite, Gunter Sandstone Member of Gasconade Dolomite, Eminence Dolomite, and Potosi Dolomite. Undifferentiated igneous and metamorphic rocks of Precambrian age underlie these units to form the basement rock, but are generally not used for drinking water in this province and will not be included in its discussion. Table 9 describes approximate thickness and lithologic characteristics for each formation.

Although different rock formations are exposed at the surface throughout this province, the Salem Plateau is generally characterized by thick sequences of carbonate rocks. The carbonate terrane lends itself to the development of karst topography features. Karst refers to the process of forming features such as caves, springs, losing streams, and sinkholes by the dissolution of subsurface material by slightly acidic groundwater. Of the more than 5,500 known caves in Missouri, the majority are located in this province, and the largest springs in the state discharge from the Potosi, Eminence or Lower Gasconade formations where they outcrop in this region. Sinkholes and losing stream segments provide direct conduits for surface flow to be channeled underground. This allows the groundwater to be recharged rather quickly, however, and also provides contaminants a direct route to the aquifer.

GROUNDWATER QUALITY

WATER TYPE

The Ozark Aquifer is characterized by water that is a calcium - magnesium bicarbonate type (figure 12). Varied concentrations of the calcium or magnesium cations determine the dominant element, and there is usually a transition zone between areas of differing types (Imes and Davis, 1991). The presence of Pennsylvanian shales and sandstones in the north-central part of the province can influ-

SYSTEM	SERIES	GEOLOGIC UNIT	THICKNESS (FEET)	LITHOLOGY
		Loess	0-40	windblown silt
Quaternary		Residuum	0-100	weathered bedrock, soil
Pennsylva-nian	undifferen-tiated		0-150	primarily shales and sandstones
Mississip-pian	undifferen-tiated		0-150	primarily limestones
Ordovician	Mohawkian	Kimmswick Limestone	50-275	heavily burrowed gs to med gs to ms
		Decorah Formation	0-40 (25avg)	cherty dolo or ls with thin sh partings
		Plattin Limestone	45-400	ms to gs to honeycombed ls
		Joachim Formation	50-300	interbedded ss and dolo to shaly dolo
		Dutchtown Formation	20-170	thinly bedded ls and dolo to dolomitic ss, organicparticles and hydrocarbons
		St. Peter Sandstone	10-100	well sorted, frosted, rounded quart-zose sand, massive bedding
	Whiterockian	Everton Formation	0-120	sandy dolo to massive ss
	Canadian	Smithville Dolomite	0-150	dolo with small amounts of chert
		Powell Dolomite	150-175	med-finely crystalline dolo with thin beds of green sh and ss
		Cotter Dolomite	200 (Avg)	med-fine crystalline cherty dolo
		Jefferson City Dolo	200 (Avg)	med-finely crystalline dolo
		Roubidoux Formation	170 (Avg)	ss to cherty, sandy dolo
		Gasconade Formation	Upper 40 Lower 250	chert-free med crystalline dolo with massive bedding
		Gunter Sandstone	25-30 (Avg) to sandy dolo	med-grained quartzose ss
Cambrian	Upper Cambrian	Eminence Dolomite	220 (Avg)	med-massively bedded med-coarse grained dolo with varying amounts and types of chert
		Potosi Dolomite	30-300 (200 Avg)	massively bedded, med-fine grained dolo, fresh surfaces have bituminous odor
dolo - dolomite	ss - sandstone	ms - mudstone	gs - grainstone	ls - limestone sh - shale

Table 9. Stratigraphy of Salem Plateau groundwater province rocks. Descriptions after Thompson, 1991 and Howe, et al, 1961.

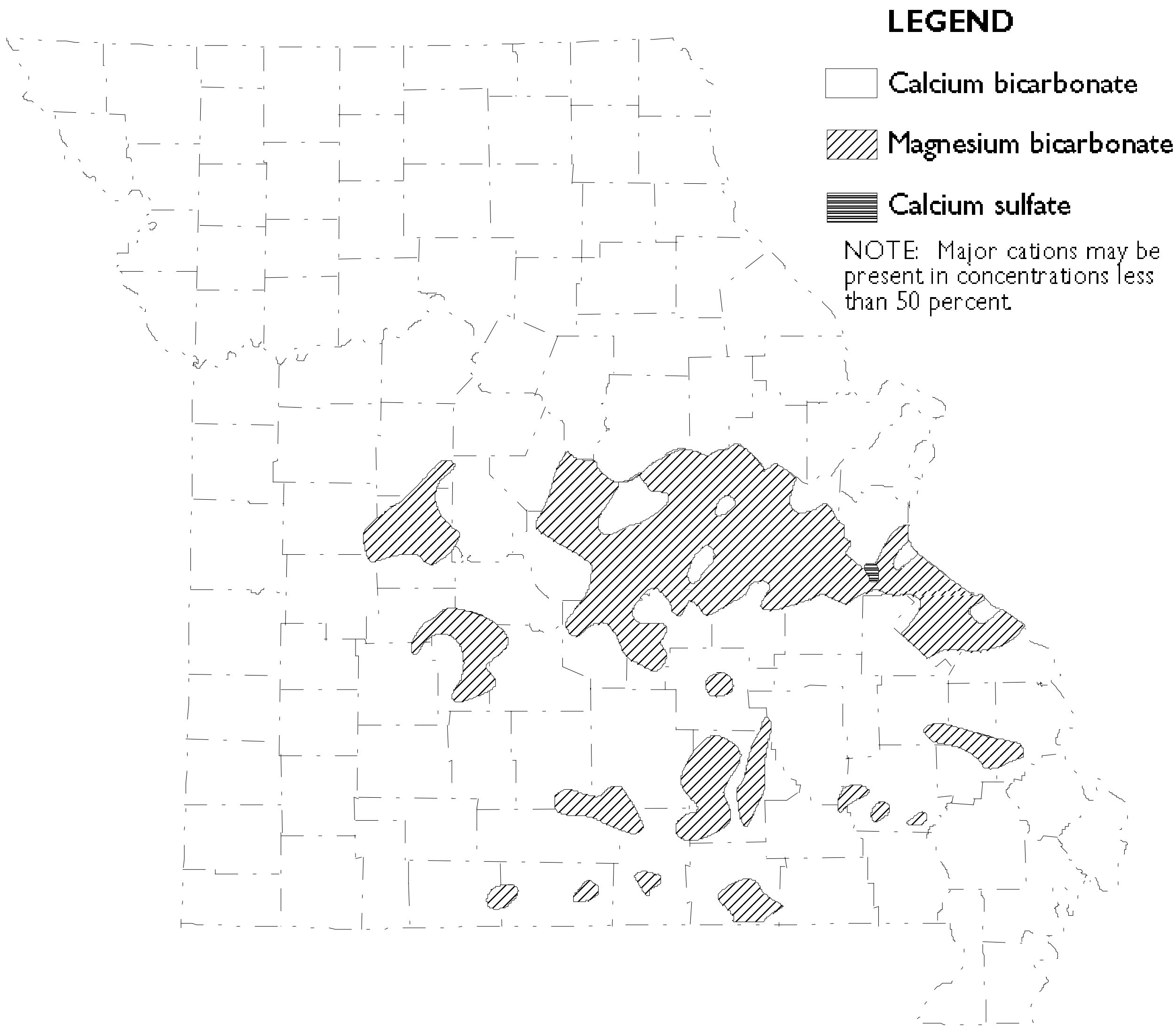


Figure 12. Salem Plateau groundwater province - Ozark Aquifer water type. (Data Source: Imes and Davis, 1991.)

ence water type on a local scale to reflect a higher concentration of sulfate or iron.

TOTAL DISSOLVED SOLIDS

Total dissolved solids (TDS), or the quantity of minerals dissolved from the rock, generally remains below the Missouri Safe Drinking Water Law recommended limit of 500 milligrams per liter (mg/l) throughout the province (figure 13). Exceptions to this are the area adjacent to what is termed the freshwater/saline-water interface at the northeastern and western edges of the province. In these areas, TDS can exceed 1,000 mg/l, and be as high as 10,000 mg/l. For comparison, water is generally categorized as fresh water with concentrations ranging from 0 to 1,000 mg/l, brackish with concentrations from 1,000 to 10,000 mg/l, saline with concentrations from 10,000 to 100,000 mg/l, and brine with more than 100,000 mg/l total dissolved solids (Freeze and Cherry, 1979). Generally, total dissolved solids are cumulatively higher due to one or two particular constituents, which are typically sodium, chloride, or sulfate.

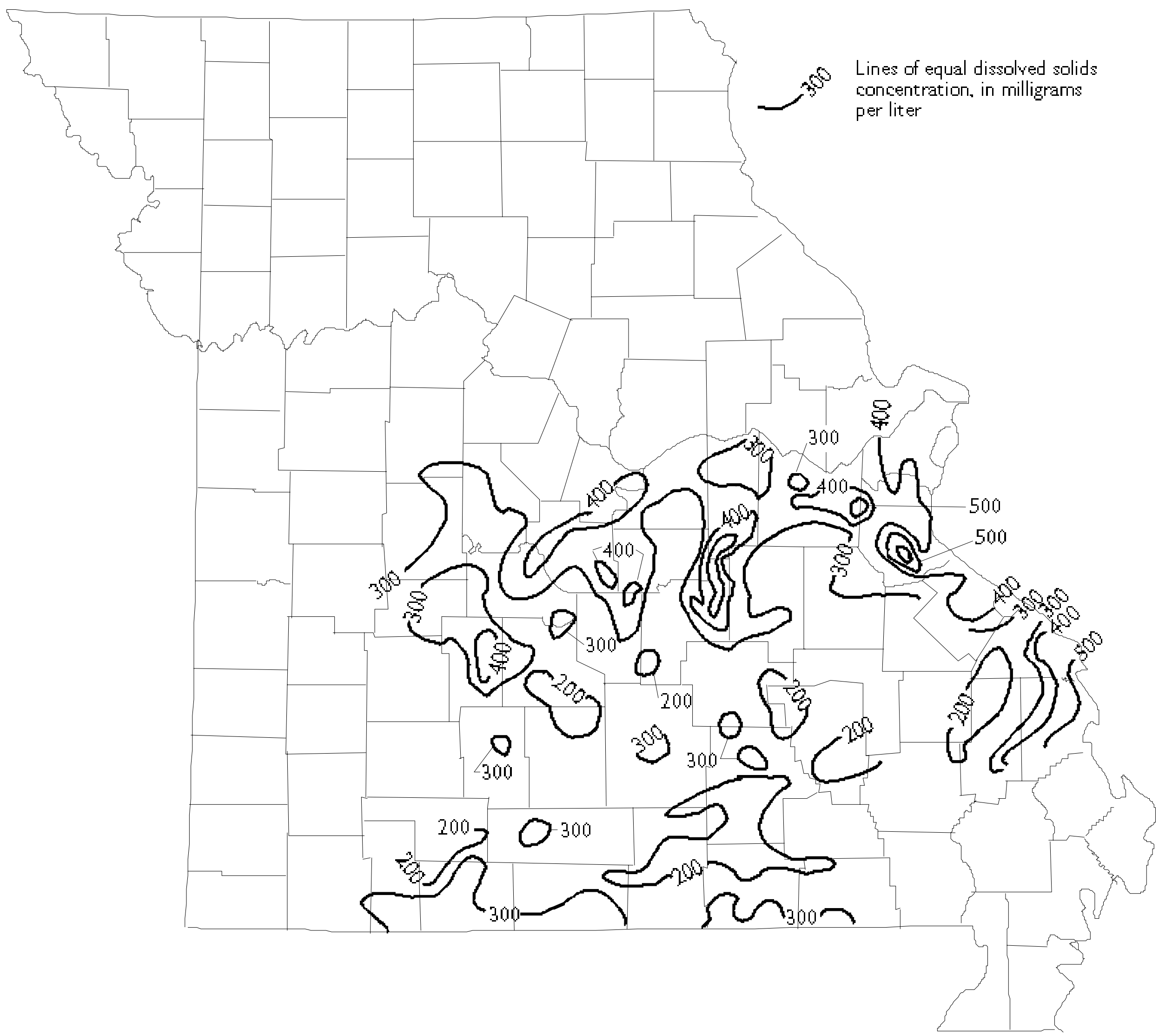


Figure 13. Total dissolved solids concentration of the Ozark Aquifer in the Salem Plateau groundwater province. (Data Source: Imes and Davis, 1991.)

SULFATE AND CHLORIDE

Figure 14 shows that most of the province has groundwater that contains very low concentrations of sulfate, from 1 to 50 mg/l. However, where there are Pennsylvanian shales and sandstones present at or near the surface, locally high concentrations of sulfate can be found. The oxidation of sulfide minerals occurring in conjunction with these formations may be the reason for the higher concentrations (Miller et al, 1974). This is true in southern Gasconade, northeastern Phelps, and central Jefferson counties where sulfate can be as high as 500 mg/l. Amounts of sulfate higher than the Missouri Safe Drinking Water Law recommended secondary maximum contaminant level of 250 mg/l can impart an unpleasant taste to the water as well as act as a laxative upon the human digestive system. Figure 15 shows that concentrations of chloride throughout the Salem Plateau groundwater province are generally very low, from 1 to 10 mg/l. Locally high concentrations, as much as 1,000 mg/l, can occur where the groundwater is in proximity to highly mineralized zones, such as the "freshwater - salinewater interface." While

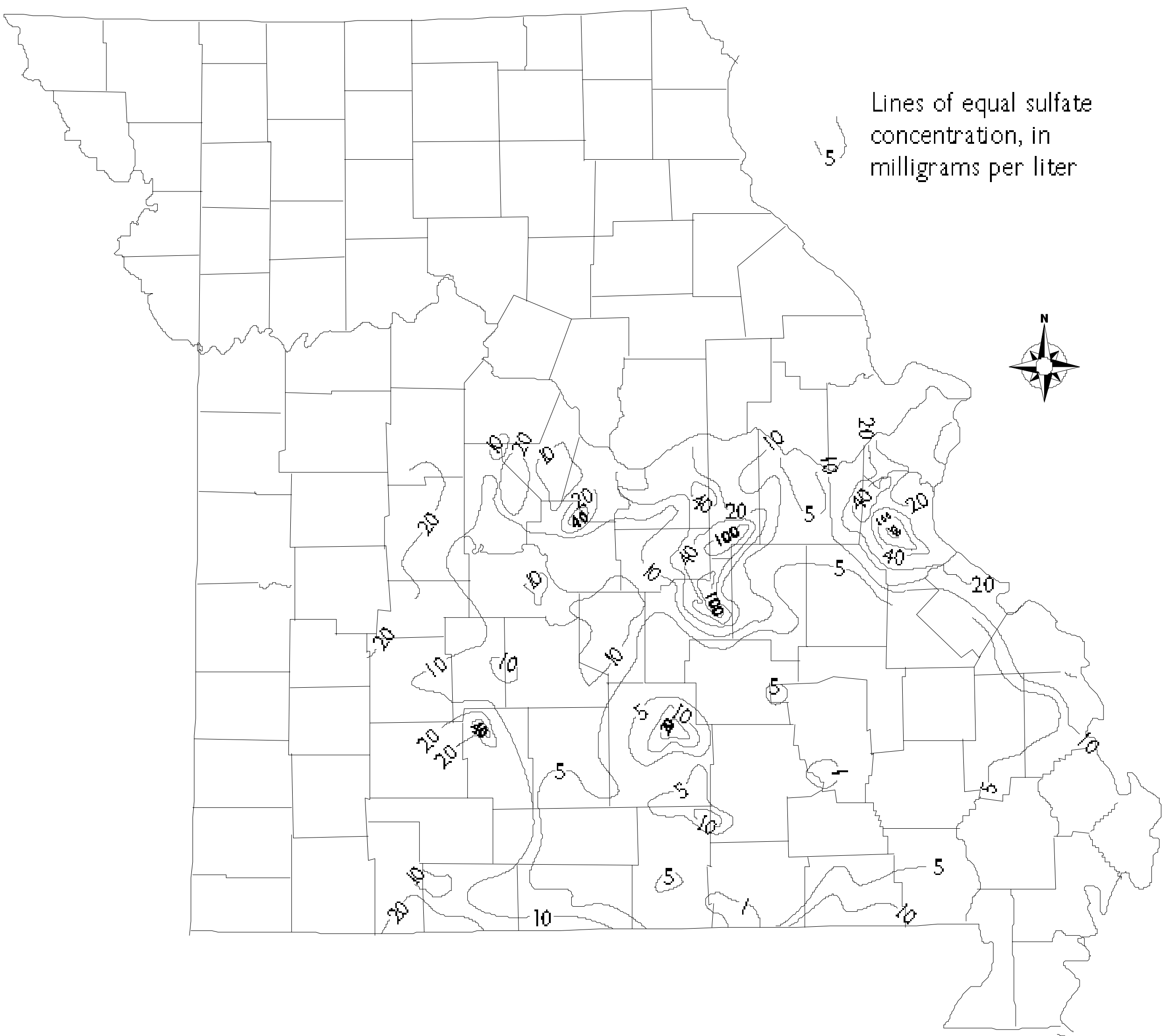


Figure 14. Sulfate - Ozark Aquifer, Salem Plateau.

the Missouri Safe Drinking Water Law's recommended secondary maximum contaminant level is 250 mg/l, it takes a concentration of about 400 mg/l to impart a salty taste to the water. Examples of typical chemical analyses of water from several municipal water-supply wells in this province are listed in table 10 and the well locations are shown on figure 16.

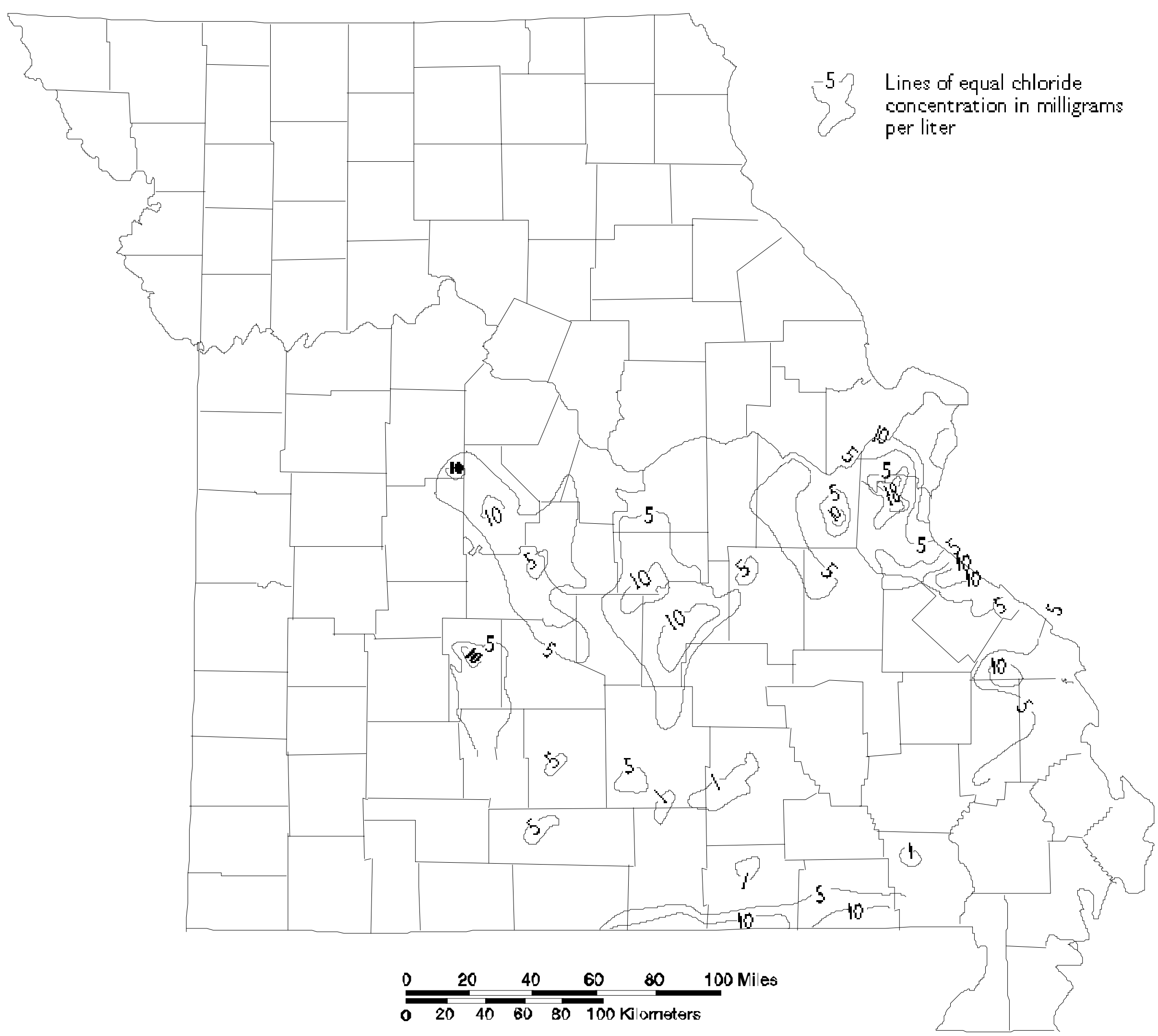


Figure 15. Chloride content of the Ozark Aquifer in the Salem Plateau groundwater province. (Data Source: Imes and Davis, 1991.)

COUNTY	CITY	pH	ALK	Fe	Mn	Na	K	Ca	Mg	N	SO_4	Cl	F	TDS	TH	Cu
Dent	Salem	7.7	210	<0.1	<0.02	2.2	0.7	42.8	25.1	0.38	<10	2.0	<0.1	251	210	0.01
Franklin	Sullivan	7.9	141	<0.1	<0.02	3.5	0.8	29.8	19.5	0.19	27.0	6.0	0.10	195	155	<0.01
Franklin	Washington	7.5	234	<0.1	<0.02	2.3	1.1	35.8	33.9	<0.05	15.0	3.0	0.10	248	220	0.02
Gasconade	Hermann	7.6	215	<0.1	<0.02	3.1	1.8	42.1	25.8	0.05	15.0	4.0	0.16	244	211	<0.01
Howell	West Plains	7.6	246	0.11	<0.02	1.8	1.4	47.5	27.2	<0.05	<10	2.0	0.11	267	231	0.01
Jefferson	Desoto	7.3	279	<0.1	<0.02	2.8	1.1	60.0	37.2	0.05	29.0	3.0	0.11	358	303	0.01
Jefferson	Festus	7.7	269	<0.1	<0.02	4.8	1.6	62.8	33.2	0.05	25.0	3.0	0.39	313	294	0.01
Laclede	Lebanon	7.6	207	0.50	<0.02	2.6	1.4	40.8	22.7	0.16	15.0	3.0	0.20	221	195	0.04
Miller	Iberia	7.4	276	<0.1	<0.02	1.9	1.6	60.0	34.6	0.05	13.0	2.0	0.20	329	292	0.01
Pettis	Sedalia	8.6	121	<0.1	0.08	3.4	3.3	37.4	11.3	0.28	30.0	6.0	1.40	207	140	0.01
Phelps	Rolla	7.5	277	<0.1	<0.02	3.1	1.1	52.9	38.5	0.05	42.0	2.0	1.10	325	291	0.08
Ripley	Doniphan	7.8	229	<0.1	<0.02	2.0	0.8	41.9	27.2	0.12	<10	<2.0	<0.2	243	217	<0.05
Taney	Hollister	7.6	234	<0.1	<0.02	0.8	0.7	39.7	31.7	<0.05	<10	<2.0	<0.1	281	230	0.01
Texas	Cabool	7.6	238	<0.1	<0.02	3.1	1.0	50.2	30.5	0.14	10.0	2.0	1.10	297	251	<0.01
Texas	Licking	7.7	165	<0.1	<0.02	1.7	1.2	35.0	19.8	0.14	10.0	2.0	0.10	208	169	0.01
Wright	Mansfield	7.6	211	<0.1	<0.02	2.8	1.1	45.9	24.8	0.08	10.0	5.0	1.20	264	217	0.02

ALK - alkalinity Fe - iron Mn - manganese Na - sodium K - potassium Ca - calcium Mg - magnesium N - nitrogen
SO_4 - sulfate Cl - chloride F - fluoride TDS - total dissolved solids TH - total hardness Cu - copper

Table 10. Chemical analyses of selected Salem Plateau province municipal water-supply wells. Analyses of disinfected finished water expressed in milligrams per liter (Missouri Department of Natural Resources, 1992).

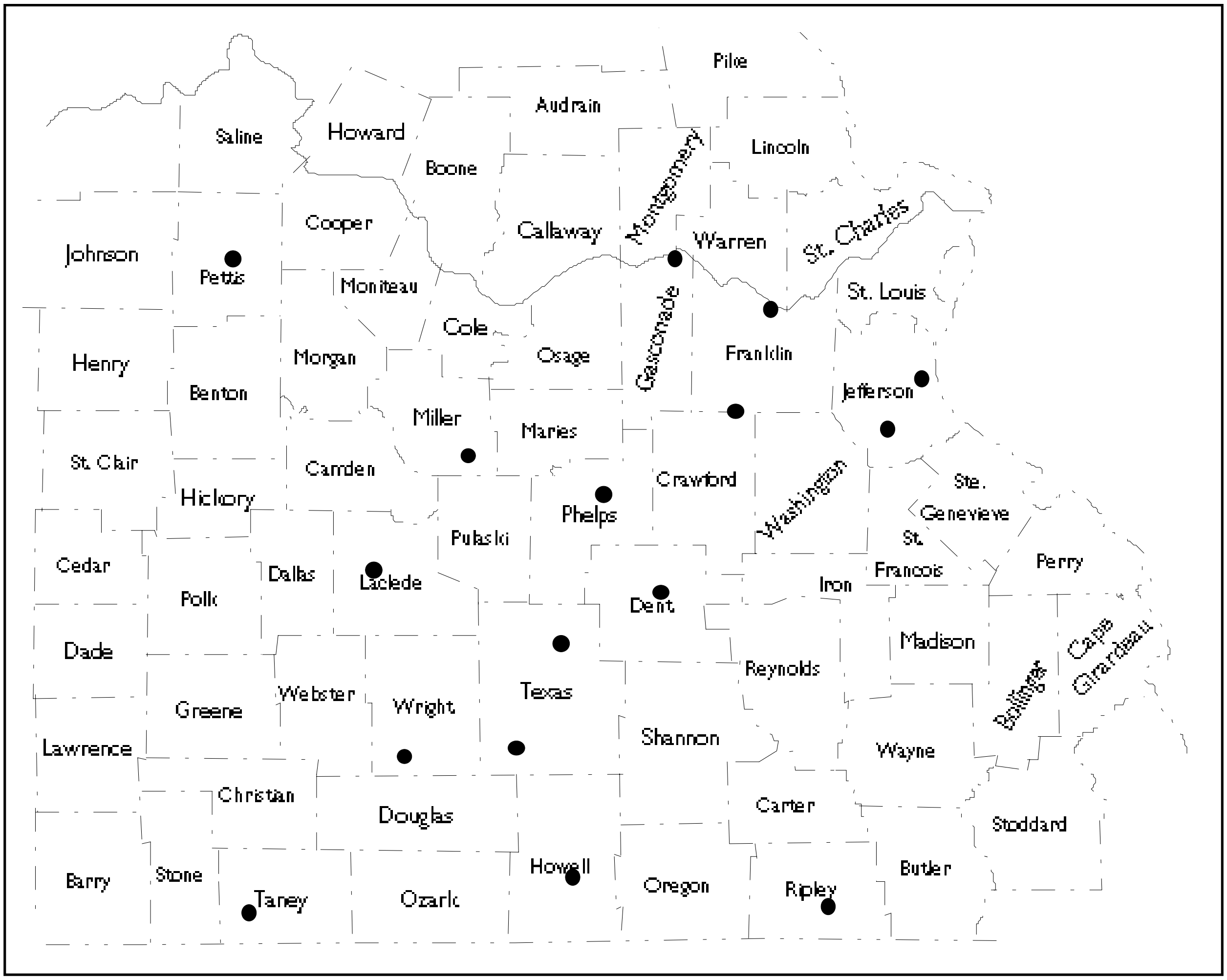


Figure 16. Approximate locations of selected municipal water-supply wells in Salem Plateau groundwater province.

OTHER INORGANICS

Other inorganic elements which may be interpreted as contamination to groundwater include trace elements such as copper, lead, iron, zinc, arsenic, cobalt, cadmium, nickel, selenium, and barium. Missouri's principal lead and zinc production areas are shown in figure 17. Figure 18 outlines the areas of iron deposits in the Salem Plateau and surrounding area. Figure 19 shows deposits of refractory clays (fire clays). While both iron and clay mining activities can readily affect surface water resources, it is also possible for contaminants associated with the mining process to infiltrate shallow groundwater and migrate laterally and vertically to other groundwater zones. Tailings piles and ponds and flooded mine areas associated with lead and zinc mining typically are sources of high concentrations of lead, zinc, sulfate, and mining by-products. Milling processes generally concentrate the ores, and once deposited in piles and ponds, the waste material is very susceptible to changing geochemical conditions that allow for rapid transport of the trace elements. Losing streams (streams that lose 30 percent or more of their flow to the subsurface) can channel water with high trace-element concentration directly into the groundwater. Flooded mine areas also experience

Figure 17. Principal lead and zinc production areas.

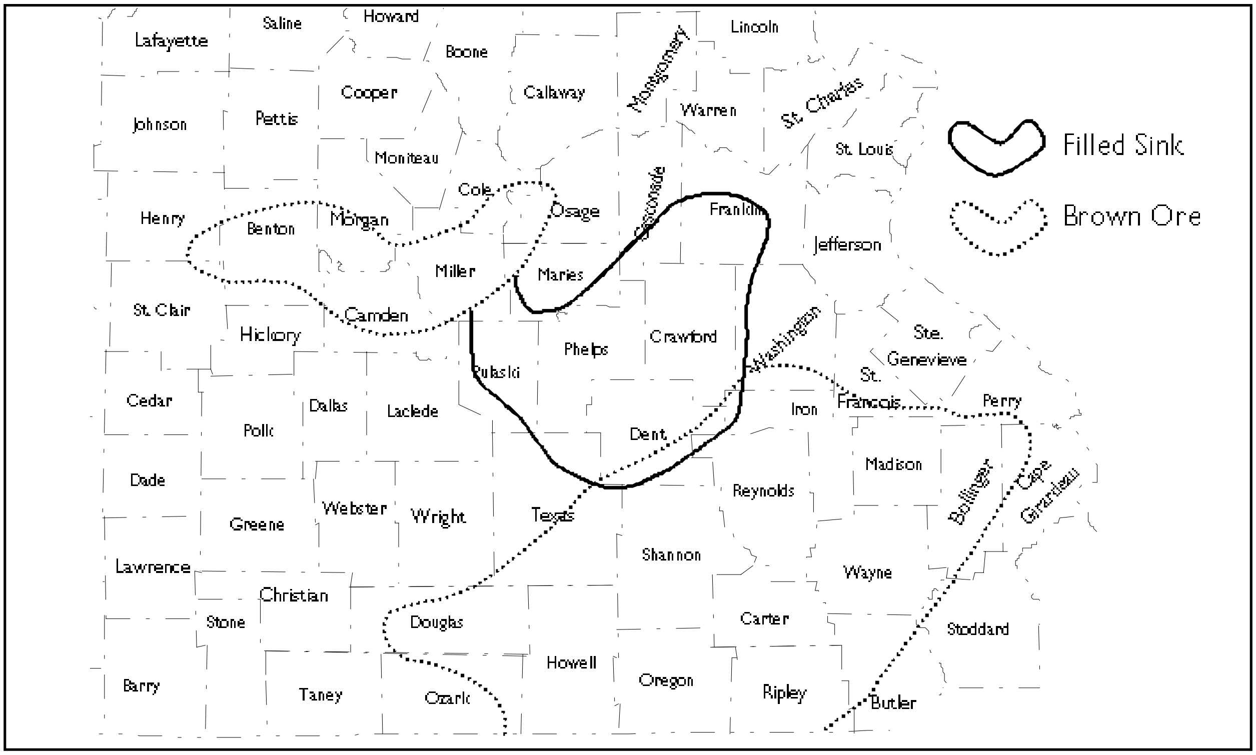


Figure 18. Iron deposits - Salem Plateau and surrounding area.

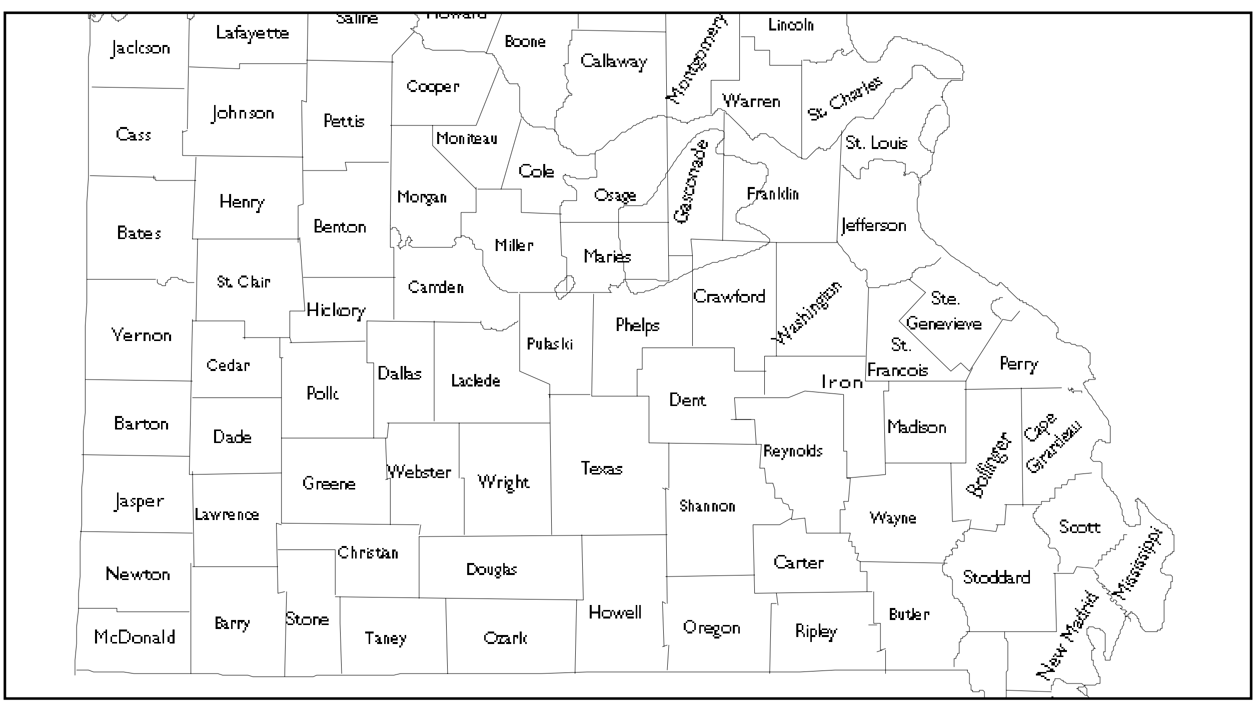


Figure 19. Non-refractory clay deposits - Salem Plateau groundwater province (after Smith, 1988).

changes in geochemical conditions which can concentrate these trace elements. However, local contamination of the groundwater near these mined areas can be quite common. A complete discussion of the findings of initial studies concerning groundwater contamination in mined areas is beyond the scope of this document, however, a publication by B.J. Smith titled *Assessment of Water Quality in Non-Coal Mining Areas of Missouri, 1988* is quite informative and thorough.

Pesticides

Pesticides have been detected in wells and springs in the Salem Plateau groundwater province during recent studies. Pesticide usage in the Salem Plateau area is generally low, averaging less than 0.01 to 0.05 kilograms per hectare per year. A 1993 National Water Quality Assessment study of the Ozark Plateau area, which includes Missouri's Salem Plateau, showed that the number of pesticide detections was higher in sampled springs than in wells. Concentrations of pesticides in all samples were generally lower than concentrations found in samples collected in other study areas (Adamski and Pugh, 1996). Occurrence of pesticides in this province is probably directly related to land use of the area surrounding the sampling location. This fact, in addition to different recharge and flow characteristics for wells and springs, would support the findings that more springs than wells contained pesticides.

Table 11 lists important criteria about each spring and well in which pesticides have been detected, along with a listing of pesticides detected and their general use throughout the area. Additionally, a summary of quarterly pesticide monitoring of public water systems in 1995 showed that of 1,300 groundwater systems tested, only four had pesticide detectable levels (MDNR-DEQ, 1995). Three of those four were located in the Salem Plateau province, and one each in Franklin, Perry, and Jefferson counties. Atrazine, alachlor, and simazine, all of which are used for emergent weed control, were the pesticides detected, although none were at concentrations above the Missouri Safe Drinking Water Law maximum contaminant levels (MCL). Flooding, delayed planting, and improved pesticide application practices probably all contributed to keeping pesticide levels under MCL (MDNR-DEQ, 1995). Use of activated carbon filters by public drinking water treatment plants and more stringent well construction regulations also decreased MCL violations. Results of required quarterly monitoring of some public water systems show a trend of very few pesticide detections in groundwater systems.

After the 1993 flood, concerns were raised over possible contamination of domestic water wells by the inundating flood waters. This concern prompted the Missouri Department of Health, in conjunction with the U.S. Centers for Disease Control and Prevention, to sample 861 domestic wells throughout the state. Atrazine, one of the most commonly used agrichemicals in the United States, was included in the list of constituents. None of the wells sampled had atrazine in concentrations above MCL (R. Lynn Young, pers comm, 1996.)

Nutrients

Nitrate, a form of nitrogen, is known to cause low oxygen problems if ingested by infants and small children. A statewide study, conducted by the Missouri Department of Health in 1994 of 861 private water-supply wells, showed that overall, approximately 8 percent of tested wells had high nitrates. Only 5 percent of drilled wells, such as those typically found in the Salem Plateau, were determined to contain high levels of nitrate (Missouri Department of Health, 1996). Some land use practices, such as the application of fertilizers, and human or animal wastes, can contribute to high levels of nitrate in the groundwater of some areas.

Total phosphorus in groundwater can also be related to land use practices as well as water-rock interactions (Davis, et al, 1995). Data collected between 1972 and 1990 show that less than 15 percent of samples from wells in this province had phosphorous at concentrations above detection levels (Davis, et al, 1995). Springs and shallow wells had higher concentrations than deep wells.

Springs with Detectable Pesticide Concentrations, Number of Pesticide Detections, Discharge, Aquifer, and General Land Use. (L/min = liters per minute; CR = row-crop agriculture; F = forest; O = orchards; P = pasture; RC = residential/commercial; RR = rural residential; Ozark = Ozark aquifer)

Local Identifier	Number of Pesticide Detections	Discharge (in L/min)	Aquifer	Percent Land Use in Basin CR	F	O	P	RC	RR
*OZ-1	3	11	Ozark	<5	<5	<5	<5	100	<5
OZ-4	3	2,684	Ozark	<5	15	<5	5	80	<5
OZ-5	2	19	Ozark	<5	90	<5	10	<5	<5
OZ-16	1	1,620	Ozark	<5	90	<5	10	<5	<5
OZ-21	1	846	Ozark	<5	50	<5	50	<5	<5
OZ-22	2	1,514	Ozark	<5	30	<5	30	40	<5
OZ-24	1	5,678	Ozark	<5	90	<5	10	<5	<5
OZ-30	1	114	Ozark	<5	50	<5	40	10	<5

* Springs not located in Missouri

Wells With Detectable Pesticide Concentrations, Number of Pesticide Detections, Depth, Aquifer, and General Land Use. (m = depth, in meters below land surfaces; CR = row-crop agriculture; F = forest; P = pasture; RR = rural residential; - = depth unknown; Ozark = Ozark aquifer)

Local Identifier	Number of Pesticide Detections	Depth (in m)	Aquifer	Percent Land Use Within 0.4 Kilometer Radius of Site CR	F	P	RR
*OZ-1	3	64	Ozark	<5	50	50	<5
*OZ-3	4	20	Ozark	<5	90	10	<5
OZ-7	2	66	Ozark	<5	10	90	<5
OZ-24	1	—	Ozark	<5	80	20	<5

* Wells not located in Missouri

Pesticides Detected in Groundwater Samples Collected From Domestic Wells and Springs in the Ozark Plateaus Province. (µg/L, micrograms per liter)

Pesticide	Number of Detections	Range of Concentrations (in µg/L)	General Use
Atrazine	14	0.001- 0.015	Selective and non-selective weed control
Prometon	11	.001- .13	Total vegetation control
Tebuthiuron	7	.005- .23	Total vegetation control
P,P' DDE	4	.002- .003	None (metabolite of DDT)
Metolachlor	3	.002- .003	Pre-emergent weed control in crop areas
Carbaryl	2	.012	Residential and crop insecticide
Chlorpyrifos	2	.003- .013	Residential and crop insecticide
Lindane	2	.028- .032	Crop insecticide
Propanil	2	.007- .012	Selective weed control in rice and wheat areas
Benfluralin	1	.003	Selective weed control in turf and crop areas
DCPA	1	.002	Pre-emergent weed control in crop and turf areas
Dieldrin	1	.025	Crop insecticide; no longer in use
Simazine	1	.011	Pre-emergent weed control in crops and turf areas
Trifluralin	1	.003	Pre- and post-emergent weed control in crop areas

Table 11. Salem Plateau wells and springs with pesticide detection. (Modified from Adamski and Pugh, 1996.)

DISCHARGES OF LARGE SPRINGS IN MISSOURI***

(in gallons per day)

Name of Spring	County	Location	Average Discharge	Discharge	Date	Discharge	Date
Big	Carter	SW NE Sec. 6, T26N, R1E	276,000,000	840,000,000	June 1928	152,000,000	October 6, 1956
Greer	Oregon	SE SW Sec. 36, T25N, R4W	214,000,000	583,000,000	May 26, 1927	67,000,000	November 16-19, 1956
Double	Ozark	NE NE Sec. 32, T24N, R11W	*100,000,000	150,000,000	April 7, 1965	30,000,000	November 16, 1964
Bennett	Dallas	SE NW Sec. 1, T34N, R18W	100,000,000	**		36,000,000	November 13, 1934
Maramec	Phelps	NW SE Sec. 1, T37N, R6W	96,000,000	420,000,000	1927-28	36,000,000	August 1, 1934
Blue	Shannon	NE SE Sec. 21, T29N, R2W	*90,000,000	153,000,000	April 24, 1964	40,000,000	October 10, 1932
Alley	Shannon	NW SE Sec. 25, T29N, R5W	81,000,000	**		35,000,000	October 1934
Welch	Shannon	SE SE Sec. 14, T31N, R6W	*75,000,000	214,000,000	June 22, 1924	45,000,000	August 24, 1964
Boiling	Pulaski	SE NW Sec. 33, T37N, R10W	*68,000,000	45,000,000	October 26, 1963	36,000,000	January 21, 1964
Blue	Oregon	NW SE Sec. 16, T22N, R2W	*61,000,000	65,000,000	July 18, 1935	35,000,000	August 13, 1936
Montauk	Dent	SE NE Sec. 22, T32N, R7W	*53,000,000	79,000,000	May 15, 1939	25,000,000	August 13, 1934
Hahatonka	Camden	NE SW Sec. 2, T37N, R17W	48,000,000	123,000,000	June 19-20, 1924	28,000,000	February 23, 1923
North Fork	Ozark	SW SW Sec. 28, T24N, R11W		49,000,000	July 6, 1966	43,000,000	April 8, 1966
Round	Shannon	SW NW Sec. 20, T30N, R4W	26,500,000	336,000,000	May 1933	6,500,000	December 1937
Hodgson Mill	Ozark	SW SE Sec. 34, T24N, R12W	*24,000,000	29,000,000	August 18, 1934	15,000,000	August 29, 1926

* Estimated

** Peak flows affected by runoff upstream from spring, after heavy rains.

*** Source Table 41, p. 317, Mineral and Water Resources of Missouri, 1967.

Table 12. Missouri's largest springs (after Vineyard and Feder, 1982)

Springs

The Salem Plateau physiographic province contains one of the largest concentrations of springs in the United States (Vineyard and Feder, 1982). The presence of massive sequences of highly-fractured carbonate rocks beneath highly permeable soils allows large amounts of precipitation to be stored in the aquifer. Recharge and discharge of water in this type of geologic setting can be quite rapid, thus explaining the presence of thousands of springs. Unfortunately, the same geologic characteristics that readily accommodate spring systems also provide direct conduits to groundwater for contaminants present in the recharge water. Shallow groundwater can easily become polluted as a result of contaminants introduced through karst features. It is therefore important to consider a poor quality of spring water as a possible indication of future contamination in the deeper aquifers.

Because of the rapid recharge characteristics of springs, they tend to have highly variable water quality. Periodic sampling might show general trends in the quality, however, certain short-lived occurrences of contaminants might be missed during routine sampling due to the rapid cycling of groundwater. Springs in Missouri are considered to be non-thermal, with water temperature approximating the mean annual temperature of the air at their location. This means that normal water temperature at a spring should range between 55^0 F and 59^0 F. Because most spring water contains fecal coliform bacteria, it is not recommended that springs be used for drinking water sources unless filtration and chlorination is utilized. Nearly all springs in this province also show evidence of nitrate, generally in concentrations less than 10 mg/l. Iron is present in most spring water in low quantities. Water type is calcium-magnesium bicarbonate due to the geologic formations in which the water resides and travels. Due to shorter residence time in the subsurface, springs typically will contain between 25 and 50 percent less total dissolved solids than wells in the same area. Dissolved mineral content in spring water will increase as discharge decreases and residence time of the water in the formation lengthens.

Most of the larger springs in the Salem Plateau province issue from the Gasconade, Eminence, and Potosi Dolomites. Table 12 lists the fifteen largest springs with their locations and average flow measurements. For complete descriptions of individual springs in Missouri, the author highly recommends *Springs of Missouri*, by Jerry D. Vineyard and Gerald L. Feder, Water Resources Report 29, Missouri Department of Natural Resources, 1982.

ST. FRANCOIS MOUNTAINS

LOCATION AND GEOLOGY

The St. Francois Mountains groundwater province includes all or part of six counties in southeastern Missouri (figure 20). Igneous, metamorphic, and sedimentary rocks all crop out in or near this province making it the most rugged topography in the state. The center of the province, the St. Francois Mountains, is composed of Precambrian granites and felsites with local occurrences of other igneous rocks. Age dating has shown these rocks to range between 1.4 and 1.45 billion years old. Missouris highest point, Taom Sauk Mountain, at an elevation of 1,772 feet above mean sea level (msl), is the focal point of the mountains. Outlying knobs, hills, and ridges of Precambrian material flank the central igneous outcrop.

Mineralization during Precambrian times formed the iron ores hematite and magnetite near the surface in Iron and St. Francois counties, and at great depth in Washington County (Howe et al, 1961). These and other mineral deposits have made this area one of the most productive ore regions in the nation. Surrounding the main outcrop are sandstones of Cambrian age, occurring in annular patterns that dip away from the mountains and lie beneath younger Paleozoic sediments throughout the rest of the state. Rocks included in the St. Francois Mountains groundwater province have previously been defined as the St. Francois confining unit and the St. Francois aquifer (USGS, 1994). Included in this groundwater province, in descending order, are the St. Francois confining unit comprised of the Derby-Doerun Dolomite and Davis Formation, and the St. Francois aquifer including the Bonneterre Formation and Lamotte Sandstone. Precambrian igneous rocks underlie this sequence of rocks but are rarely utilized for drinking water and will not be included in the discussion of this province. Table 13 describes the stratigraphic location, thickness, and lithology of each of these formations.

GROUNDWATER QUALITY

WATER TYPE

Groundwater type in the St. Francois Mountains groundwater province area is somewhat varied. Mineral characteristics of the rock formations are reflected in the different water types. Predominantly, a magnesium bicarbonate or a mixed bicarbonate with magnesium as the dominant cation type exists throughout the province (figure 21). Exceptions are a small area in southern St. Francois and northern Madison Counties that can be classified as calcium sulfate groundwater. Here, the presence of metallic ores and the subsequent oxidation of some of their minerals probably accounts for this different water type. Calcium bicarbonate groundwater is present in isolated pockets in the central and eastern parts of the province (Imes and Davis, 1991).

TOTAL DISSOLVED SOLIDS

The amount of minerals dissolved from the rock, or total dissolved solids, generally is less than 500 mg/l throughout the province (figure 22). Typically, dissolved-solids concentrations of 300 to 400 mg/l are common but locally higher or lower concentrations are present.

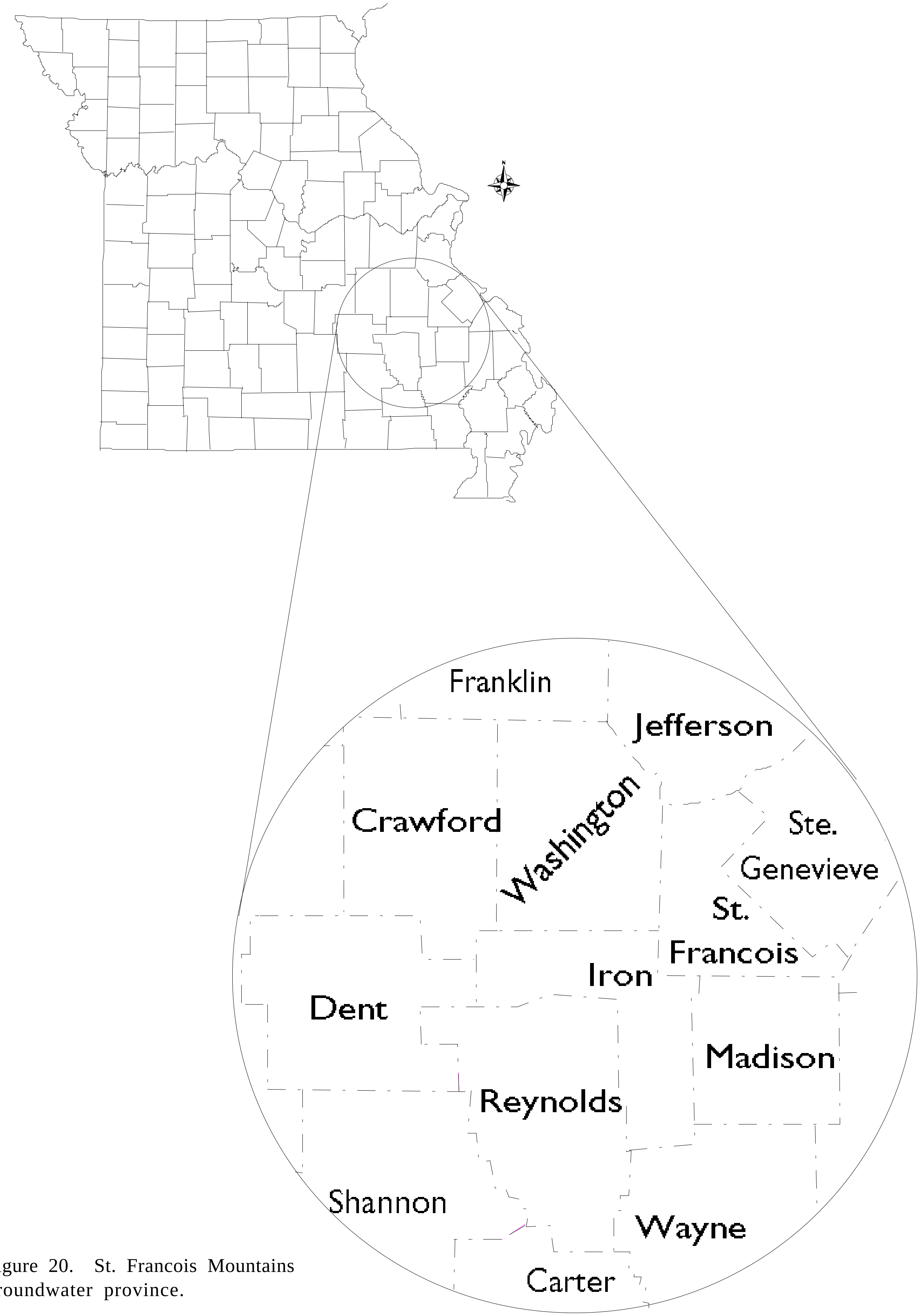


Figure 20. St. Francois Mountains groundwater province.

SYSTEM	SERIES	GEOLOGIC UNIT	THICKNESS (IN FEET)	LITHOLOGY
Cambrian	Upper Cambrian	Derby-Doerun Dolo	0-200 (150 avg)	med bedded dolo, silt, sh; chert-free dolo with glauconite in lower part
		Davis Formation	75-225 (170 avg)	Dolomitic shale, silt, fine-grained ss, dolomitic and ls conglomerate
		Bonneterre Formation	175-535 (400 avg)	med-fine grained dolo, local occurrences of ls and sh, lower sandy phase may be replaced by interbedded dolo and clastics
		Lamotte Sandstone	0-440	quartzose ss grades into arkose and pebble conglomerates
Pre-Cambrian		Igneous felsites and granites and metamorphic meta-sediments		
Dolo - dolomite	Silt - siltstone	Sh - shale	Ss - sandstone	Ls - limestone

Table 13. Stratigraphy of St. Francois Mountains groundwater province (modified from Howe, et al, 1961).

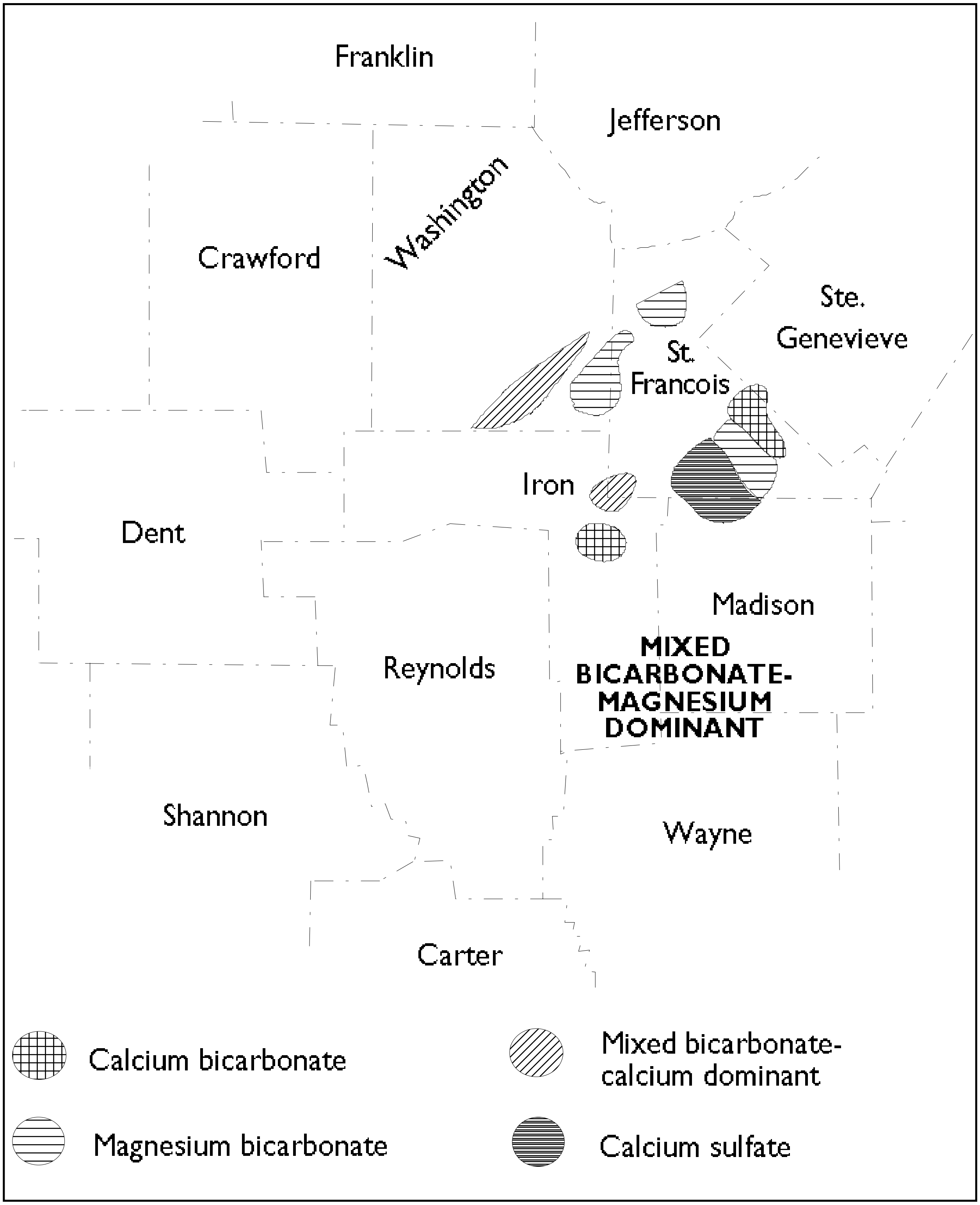


Figure 21. Water Type - St. Francois Aquifer (Data Source: Imes and Davis, 1990).

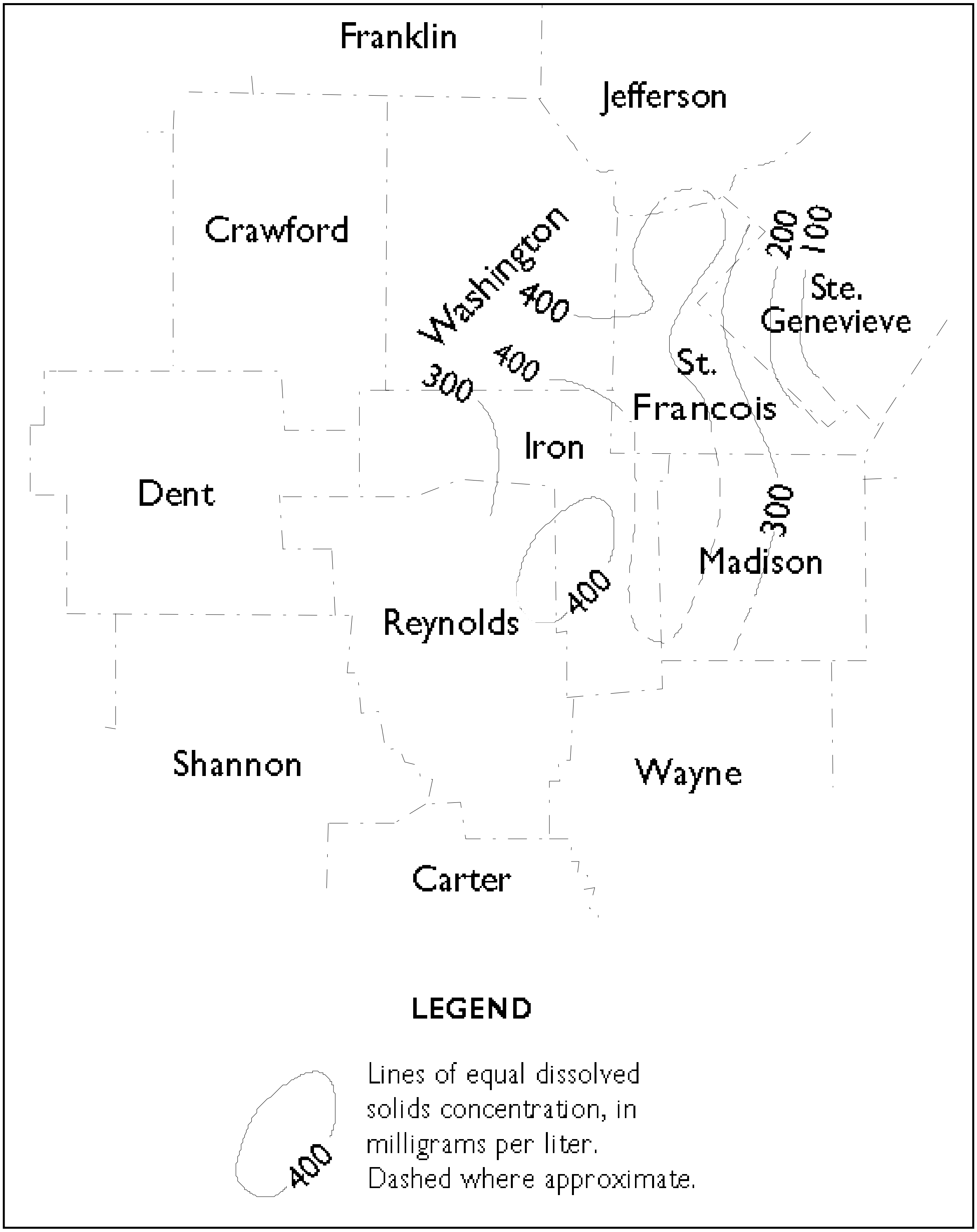


Figure 22. Total dissolved solids - St. Francois Aquifer (Data Source: Imes and Davis, 1991).

SULFATE AND CHLORIDE

Concentrations of sulfate in the St. Francois Mountains groundwater province are generally between 2 and 100 mg/l (Imes and Davis, 1991). The highest levels of sulfate are located near the northern edge of the St. Francois Mountains in southwestern St. Francois County (figure 23). However, the Safe Drinking Water Law recommended secondary maximum contaminant level of 250 mg/l is rarely exceeded. Oxidation of mineral deposits in the area is the probable source of the sulfate. Chloride concentrations in this province occur in patterns that somewhat mimic the sulfate distribution (figure 24). Concentrations from 5 to 40 mg/l are common, with the highest concentrations near the periphery of the mountains. Figure 25 and Table 14 show locations and chemical analyses of some selected municipal water-supply wells in the St. Francois Mountains groundwater province.

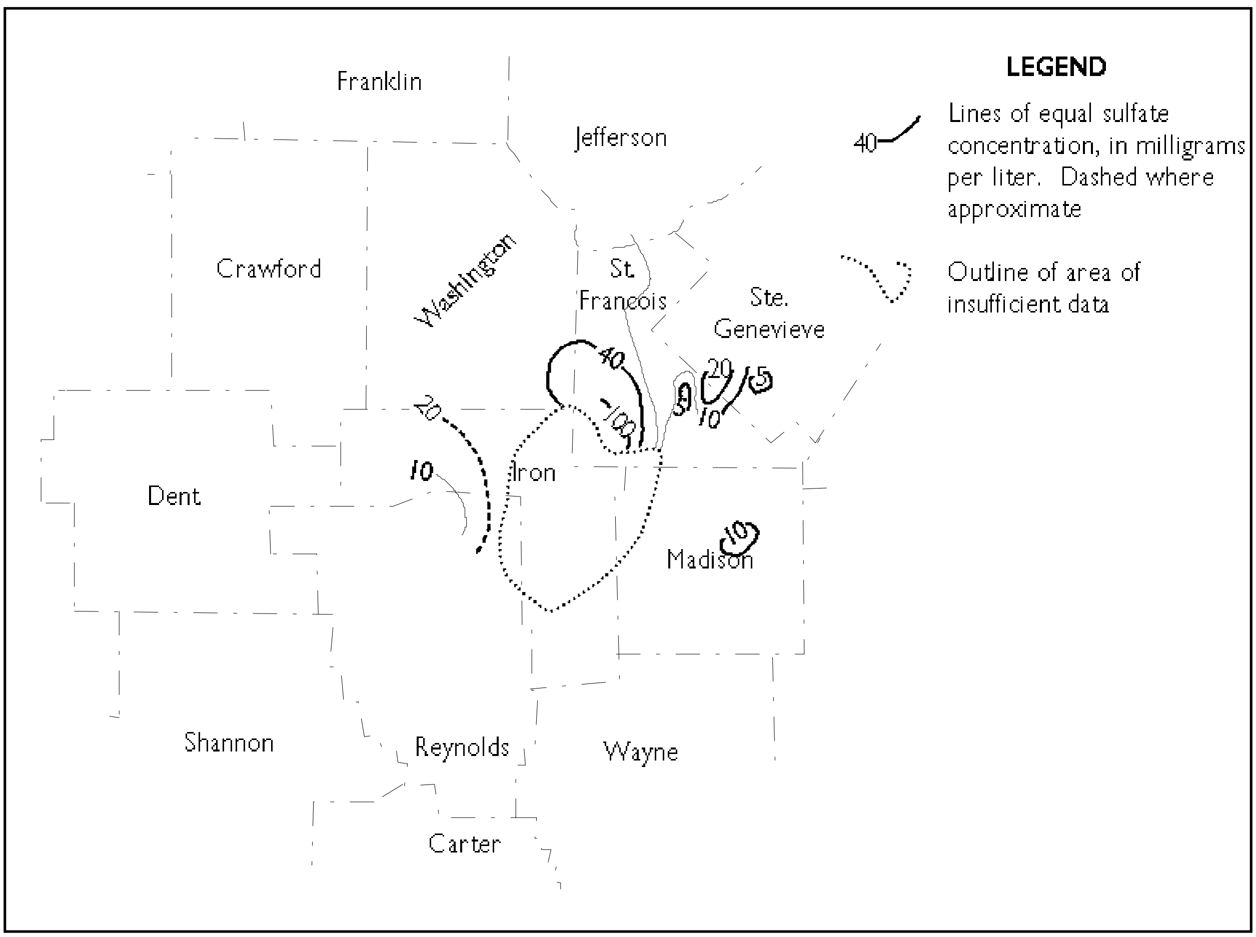


Figure 23. Sulfate - St. Francois Aquifer (Data Source: Imes and Davis, 1990).

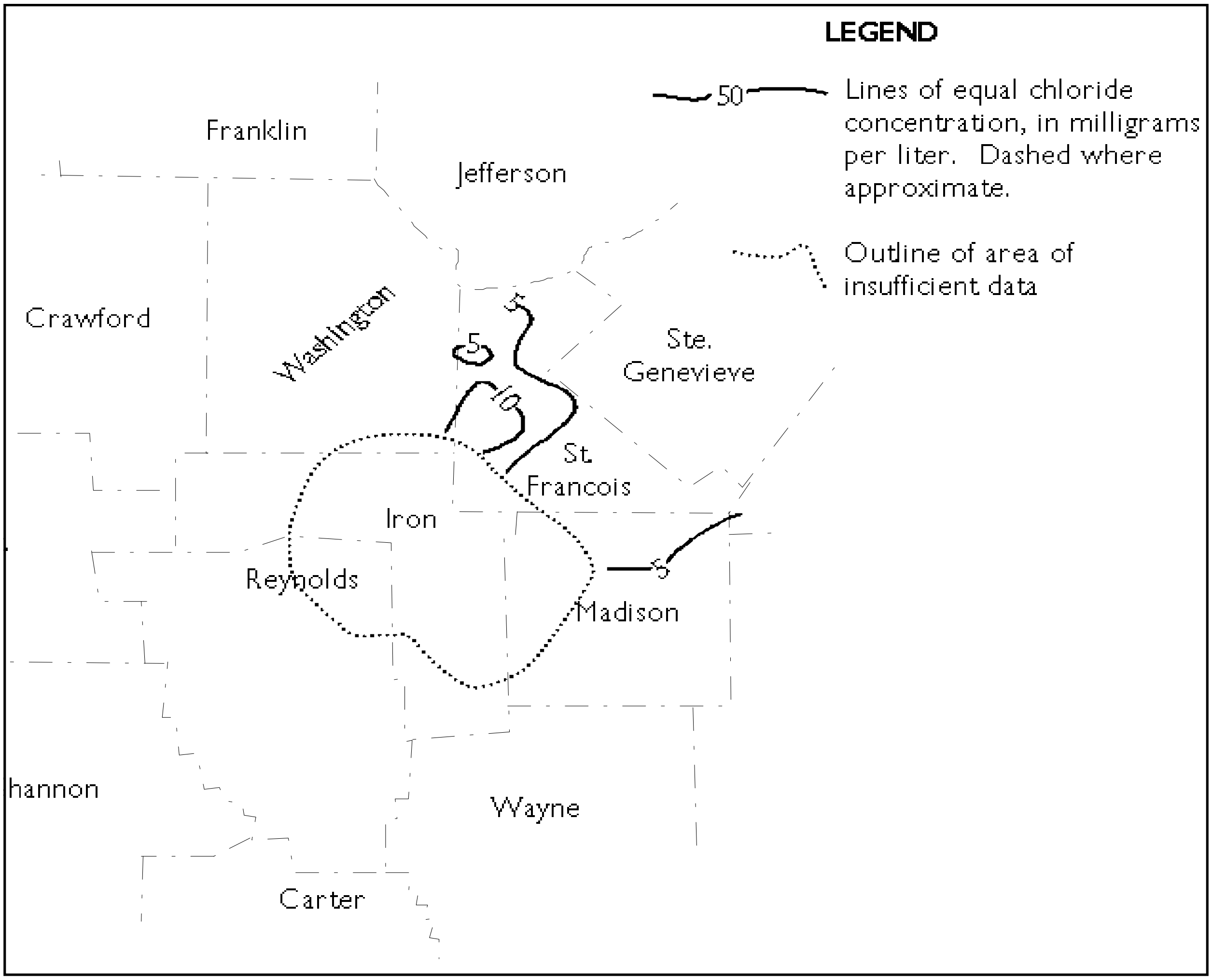


Figure 24. Chloride - St. Francois Aquifer (Data Source: Imes and Davis, 1990).

Other Inorganics

Metallic minerals and trace elements such as copper, lead, iron, zinc, arsenic, cobalt, cadmium, nickel, selenium, and barium are often found in groundwater near areas where mining of these minerals occurs. Figure 26 shows the ore deposits in the St. Francois Mountains province vicinity. These ores are closely associated with the igneous rocks that form the mountains. Unfortunately, tailings piles and flooded mines, particularly in lead and zinc mining areas, provide sources of high concentrations of lead, zinc, sulfate, and mining by-products. Local contamination of the groundwater from these elements is quite common. A complete discussion of this subject is provided in a publication by B.J. Smith, 1988, previously referenced in this document.

Pesticides

Land use in this province is primarily forest with minor amounts of pasture. The rugged topography does not lend itself to row-cropping or high-density development, and although some application of pesticides does occur, detections in groundwater due to these uses are virtually nonexistent.

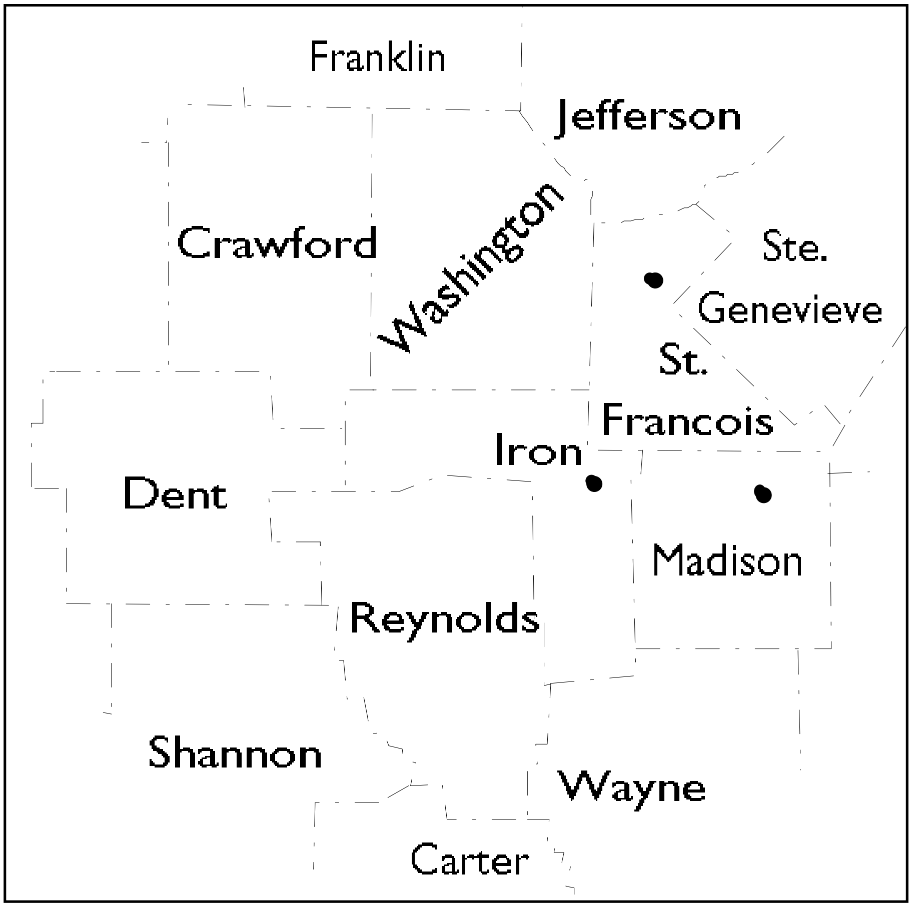


Figure 25. Approximate locations of selected municipal water-supply wells - St. Francois Mountains groundwater province.

NUTRIENTS

Nutrient concentrations in groundwater in this province are the lowest in the state due to small percentages of agricultural areas where application of fertilizers occur or areas where human or animal wastes are present.

SPRINGS

A few springs rise from the Bonneterre Formation in the eastern part of the province. Generally, the water from these springs is a calcium-magnesium bicarbonate type with calcium-magnesium ratios from 1.5 to 2.0. This value reflects the chemical makeup of the dolomite formation where the water resides and travels. Average temperature ranges from 55^0 to 59^0 Fahrenheit, mimicking Missouri's mean annual atmospheric temperature. The acidity and alkalinity (PH) ranges from 7.5 to 8.2, and nitrates and phosphates are generally very low.

COUNTY	CITY	pH	ALK	Fe	Mn	Na	K	Ca	Mg	N	SO_4	Cl	F	TDS	TH	Cu
Iron	Pilot Knob	7.7	165	<0.1	<0.02	22.6	3.8	80.1	40.3	0.18	246	20.0	1.2	563	366	<0.01
Madison	PWSD#1-N	7.8	182	<0.1	<0.02	2.6	0.9	35.8	20.8	0.10	<10	<2.0	<0.2	—	175	<0.05
St. Francois	Bonneterre	7.5	293	0.11	0.05	6.5	1.8	68.3	46.9	<0.05	100	5.0	<0.2	411	364	0.05

ALK - alkalinity Fe - iron Mn - manganese Na - sodium K - potassium Ca - calcium Mg - magnesium N - nitrogen
SO_4 - sulfate Cl - chloride F - fluoride TDS - total dissolved solids TH - total hardness Cu - copper

Table 14. Chemical analyses of selected St. Francois Mountains municipal water-supply wells. Analyses of disinfected finished water expressed in milligrams per liter (Missouri Dept. Of Natural Resources, 1992)

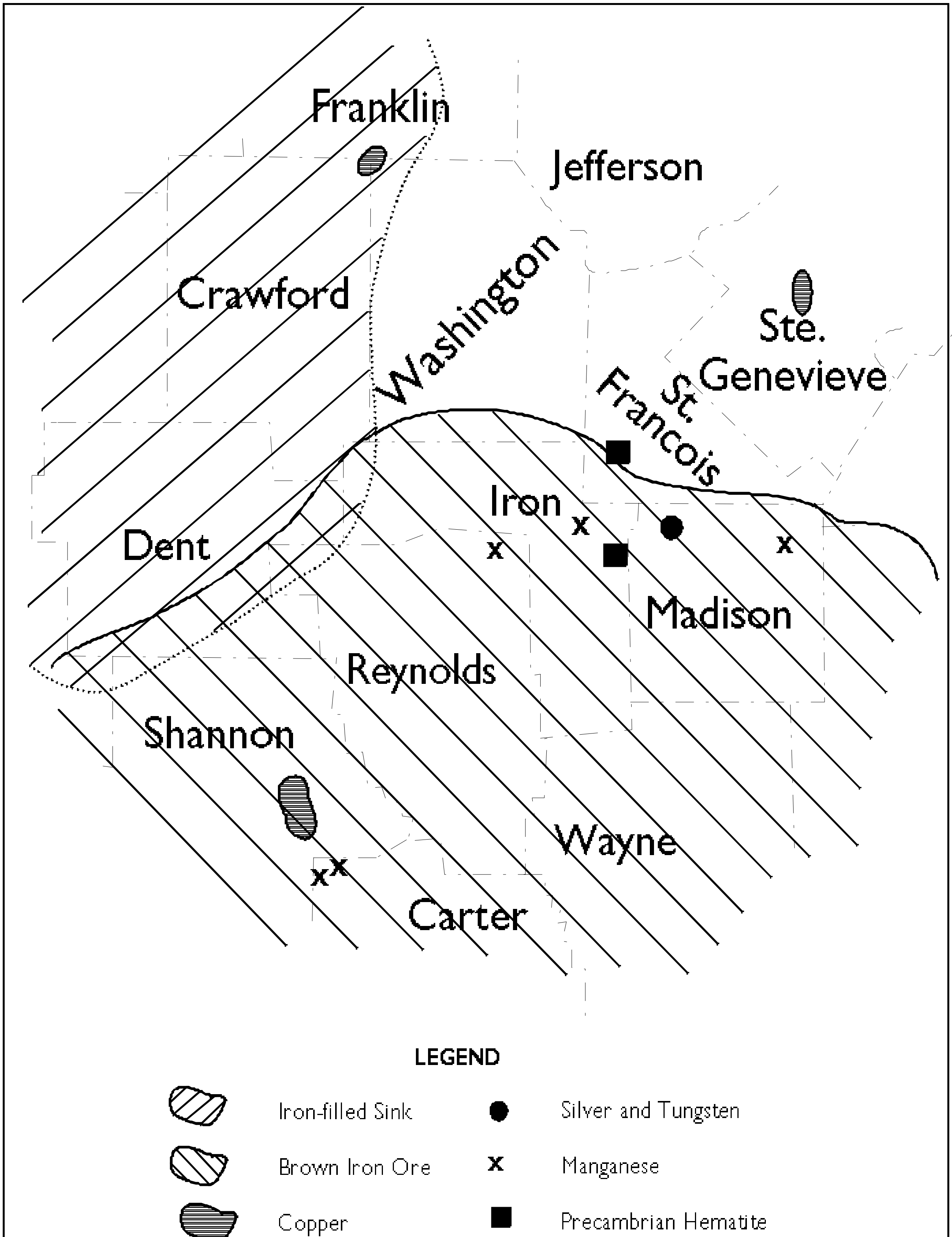


Figure 26. Ore deposits - St. Francois Mountains groundwater province and surrounding area (after Smith, 1988).

SPRINGFIELD PLATEAU

LOCATION AND GEOLOGY

The Springfield Plateau groundwater province comprises all or part of 23 counties in southwestern Missouri (figure 27). The boundary of this groundwater province basically mirrors the exposure of Mississippian rock formations at the surface. It is important to remember that the formations included in this province overlie the same sequence of rocks previously included in the Salem Plateau groundwater province. A concerted effort has been made to only include water quality information collected specifically from the shallower Springfield Plateau aquifer in this section. Wells penetrating both the Mississippian formations and the deeper Cambrian-Ordovician formations can be expected to have water quality that is a mixture of the two different strata. Additionally, it is possible that some wells, particularly municipal wells, pass completely through the Springfield Plateau aquifer and withdraw water entirely from the deeper Ozark aquifer. Though recharge to the Ozark aquifer in this area is dissimilar to recharge in the Salem Plateau, the quality of water from the Ozark aquifer here is somewhat similar to the quality of water from the Ozark aquifer in the Salem Plateau groundwater province.

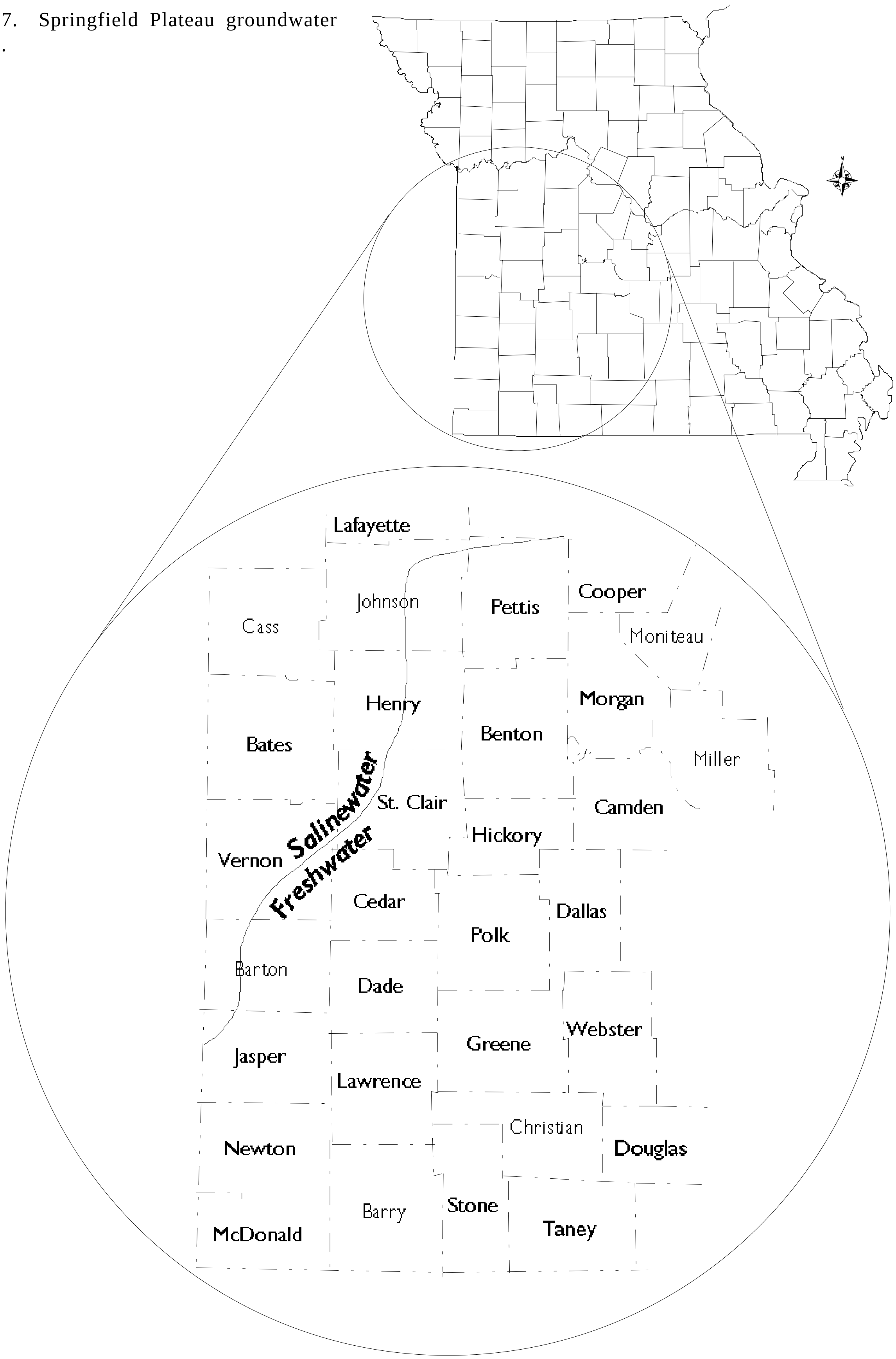
Formations included in the Springfield Plateau aquifer are, in descending order, undifferentiated Chesterian, undifferentiated Meramecian, Keokuk Limestone, Burlington Limestone, Elsey Formation, Reeds Spring Formation, and Pierson Formation. Table 15 lists the approximate thicknesses and lithologic characteristics for each of these formations. Due to the presence of limestone at the surface, this area contains numerous sinkholes, caves, losing streams, and springs. However, none of these features are quite as spectacular as those found in the adjoining Salem Plateau province. The gently rolling hills and flat-lying pastures are conducive to agricultural practices including livestock operations and small areas of row-cropping. Both of these practices can have major affects on shallow water quality as will be detailed later.

GROUNDWATER QUALITY

WATER TYPE

Primary water type in the Springfield Plateau groundwater province is calcium bicarbonate, reflecting the chemical characteristics of the rock unit in which the water resides and travels. A small area of calcium sulfate water is present in northwestern Jasper County, in proximity to mining activities, and a small pocket of sodium sulfate water is present at the northern boundary in Johnson and Lafayette counties. Though difficult to locate precisely, the freshwater-salinewater interface is present in this province and runs northeasterly, beginning in northwestern Jasper County (figure 27). This surface generally divides areas that have relatively potable water from those that have highly mineralized water. While the highly mineralized water generally resides in the deeper Ozark aquifer, the shallower Springfield Plateau aquifer may also contain slightly mineralized water. This is shown by the presence of sodium chloride type water in the northwestern part of the province (figure 28).

Figure 27. Springfield Plateau groundwater province.



SYSTEM	SERIES	GEOLOGIC UNIT	THICKNESS (FEET)	LITHOLOGY
Mississippian	Chesterian	Undifferentiated	50-200	limestone to sandstone to shale
	Meramecian	Undifferentiated	60-185	limestone, dolomitic ls to shale
		Keokuk Limestone	60-75	med crystalline limestone
		Burlington Limestone	70-100	med-coarsely crystalline chert-free to sparsely cherty gray ls
	Osagean	Elsey Formation	30	cherty ls with abundant fossil fragments
		Reeds Spring Formation	<100-225	clayey ls with alternating beds of chert
		Pierson Formation	3-75 (30-50 avg)	fine to coarsely crystalline ls with green shale partings
Dolo - dolomite Silt - siltstone Sh - shale Ss - sandstone Ls - limestone				

Table 15. Stratigraphy of Springfield Plateau province rocks (after Thompson, 1986)

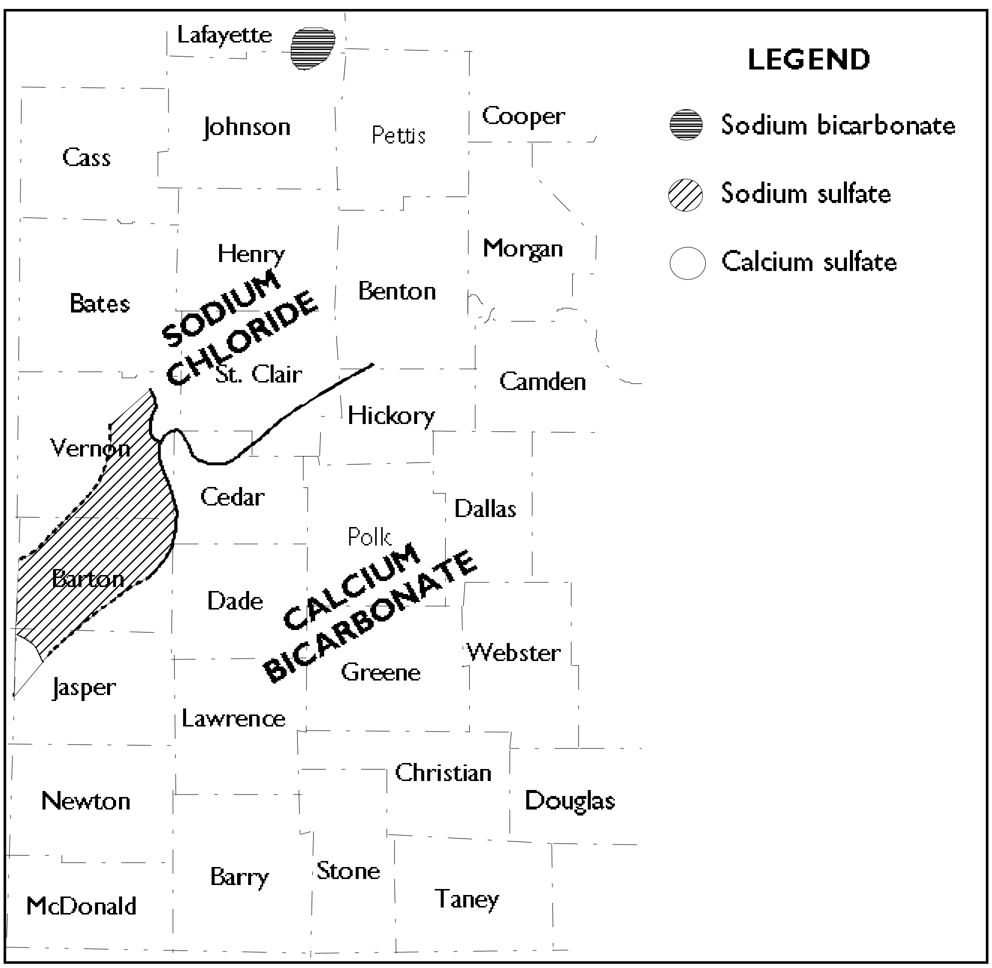


Figure 28. Water-type - Springfield Plateau Aquifer.

TOTAL DISSOLVED SOLIDS

Concentrations of total dissolved solids (TDS), or amount of minerals dissolved from rocks, range from 200 to over 5,000 mg/l (figure 29). Average values throughout the province are 200 to 300 mg/l. Near the fresh-water-salinewater interface TDS approach 1,000 mg/l and concentrations of up to 5,000 mg/l are found in the extreme northern part of the province. High sodium and chloride account for the larger TDS in these areas.

SULFATE AND CHLORIDE

Figure 30 shows the distribution of sulfate concentrations in groundwater in this province. Normal values range between 5 and 10 mg/l. Locally, sulfate concentrations of 50 to 1,000 mg/l can be found in areas where mining of sulphide minerals has occurred. This is particularly true in Jasper County, which is part of the Tri-State mining district known for its zinc production, and Barton and Vernon counties where coal was mined.

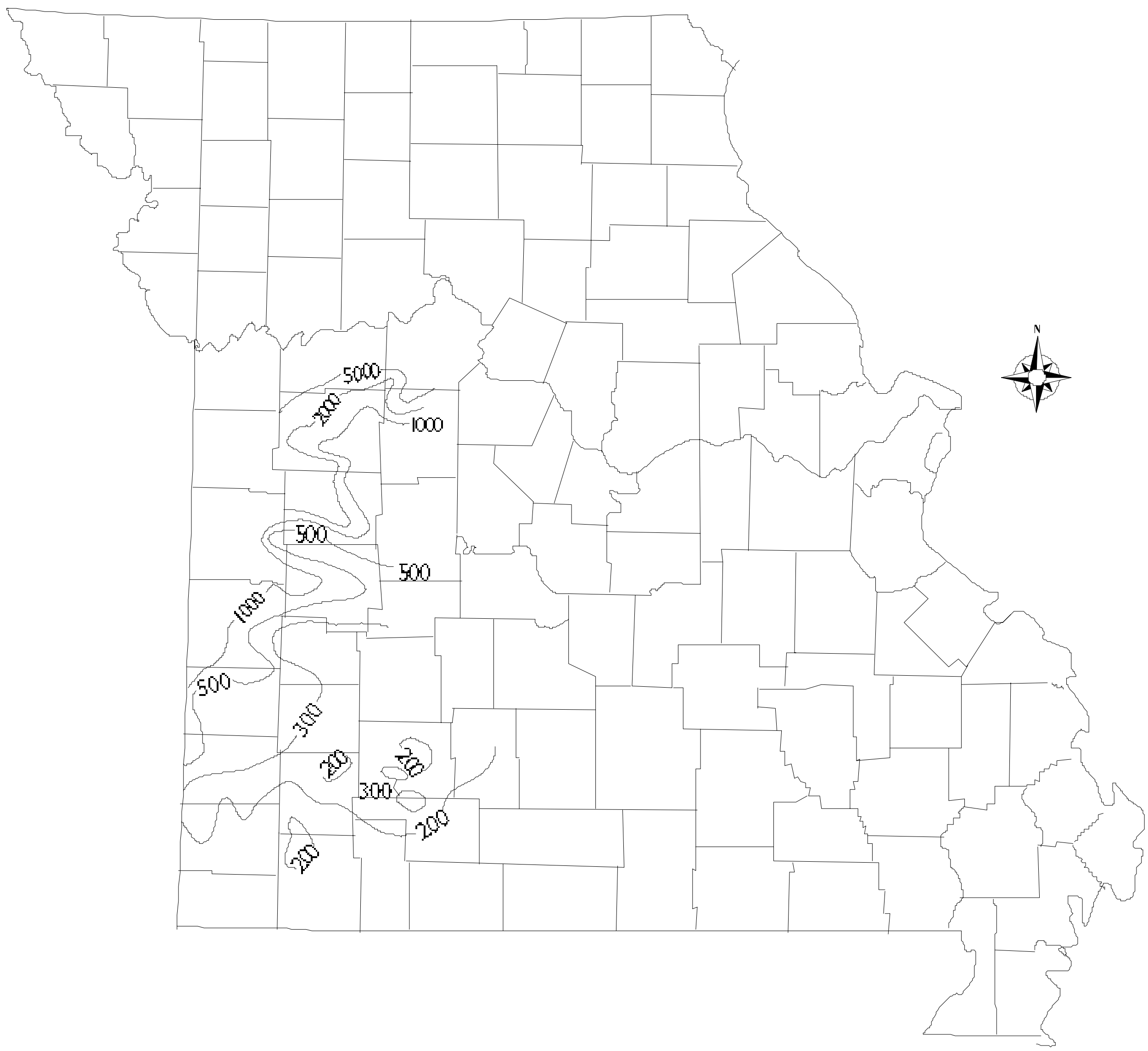


Figure 29. Total dissolved solids - Springfield Plateau aquifer.

Other effects of this mining activity will be discussed later. Chloride concentrations are generally low, averaging between 5 and 10 mg/l. In the proximity of the freshwater-salinewater interface, values may be as high as 1,000 mg/l. Also, note that extreme southern McDonald county has abnormally high chloride concentrations (figure 31, Imes and Davis, 1990). Table 16 and figure 32 list chemical analyses and show locations for several small public water supply wells in this province. Construction details of the wells indicate that the shallow Mississippian formations are their source of water. Note that calcium/magnesium ratios for each well are extremely high, indicating a calcium bicarbonate source such as limestone.

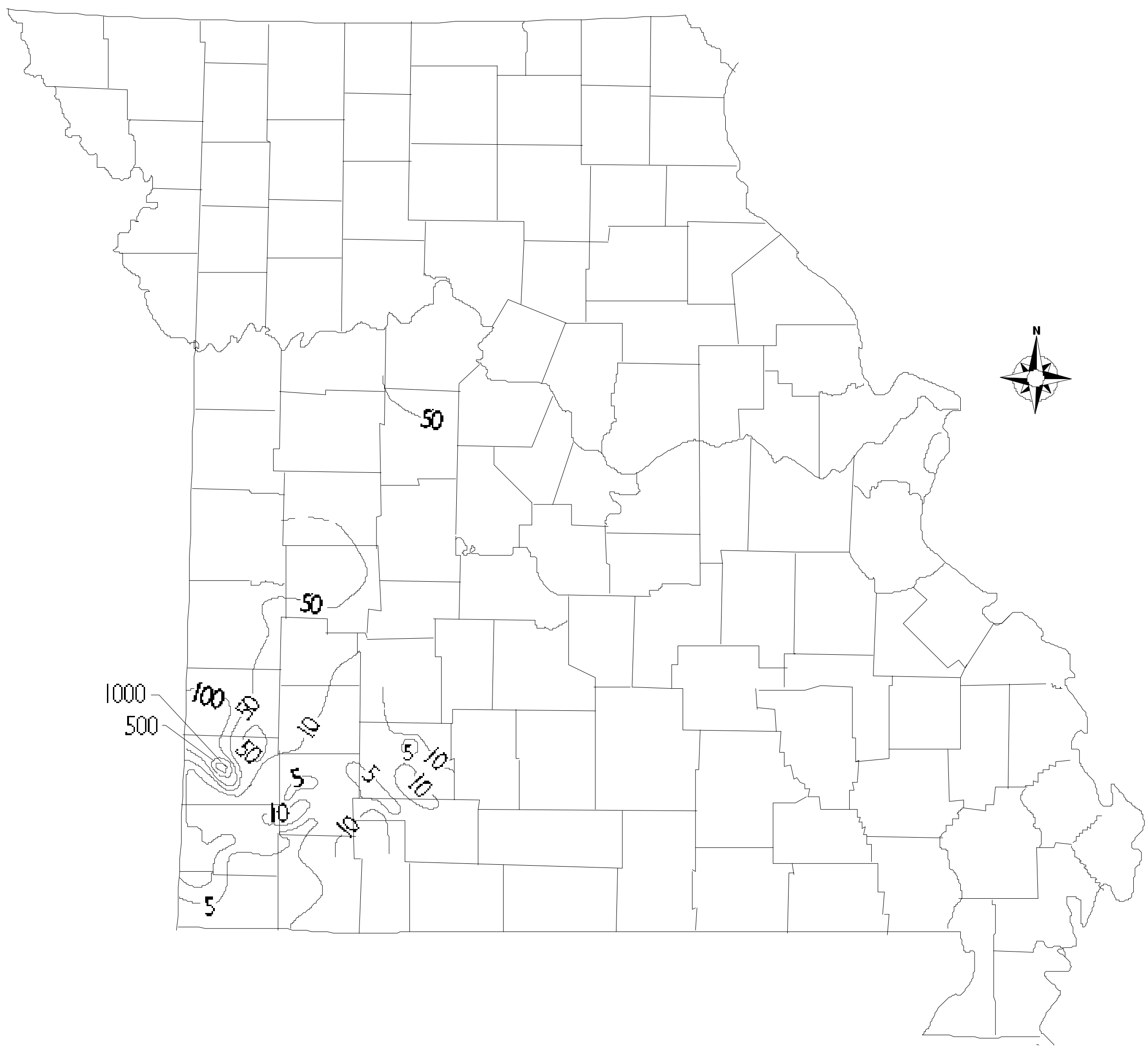


Figure 30. Sulfate - Springfield Plateau Aquifer.

OTHER INORGANICS

The Springfield Plateau province has numerous occurrences of mining activity. Lead and zinc mining were prevalent in the Tri-State mining district of Jasper and Newton counties in the past (figure 33). Iron ores were mined in McDonald and parts of Greene, Lawrence, Dade, and Polk counties, along with non-refractory clays along the northwestern boundary (figure 34). Mine wastes, tailings piles, and flooded mines all contribute to abnormally high concentrations of zinc, lead, and sulfate. Prolonged contact of the water with sulfide minerals and contamination from surface sources can be recognized by high sulfate or nitrate content. High concentrations of zinc are prevalent in water from the Mississippian limestones (Feder et al, 1969). Results of a study conducted in the Joplin area in 1971 and 1972 show that concentrations of copper in ground-water range from <1 to 330 µg/l, lead from <1 to 18 µg/l, zinc from <10 to 11,500 µg/l, cadmium from <1 to 16 µg/l and iron from <1 to 119,000 µg/l (Proctor, et al, 1974). Extensive research in the Tri-State area was reported by Feder and others in the *Water Resources of the Joplin Area, Missouri,* and B.J. Smith studied the effects of non-coal mining on ground-

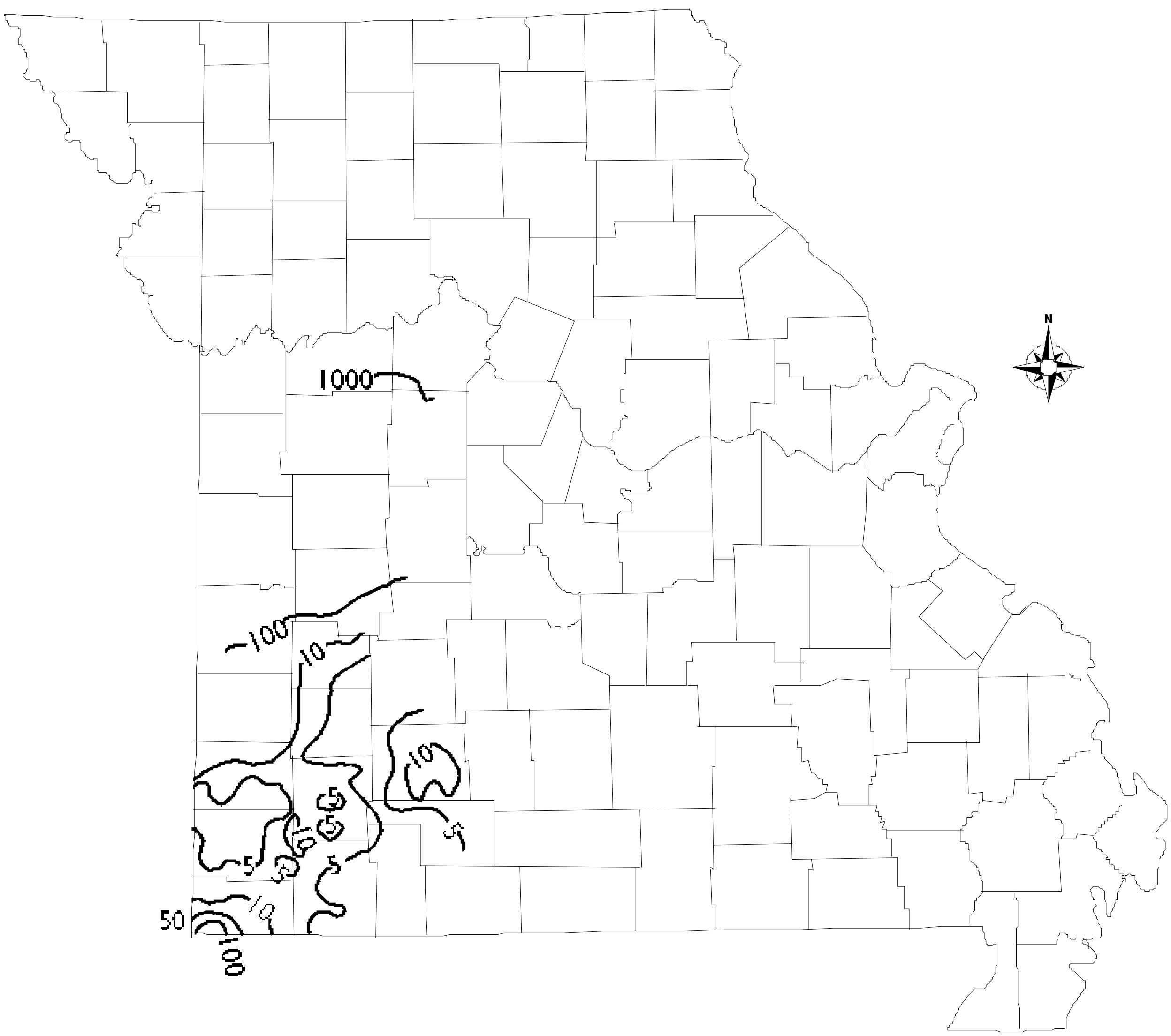


Figure 31. Chloride - Springfield Plateau Aquifer (Data Source: Imes and Davis, 1990.)

COUNTY	SUPPLY	pH	ALK	Fe	Mn	Na	K	Ca	Mg	N	SO_4	Cl	F	TDS	TH	Cu
Cedar	Stockton Hills Sub.	7.6	223	<0.1	<0.02	6.4	2.8	59.7	26.0	<0.05	36.0	11.0	0.11	303	256	<0.01
Christian	Rolling Hills MHP	7.2	238	<0.1	<0.02	7.5	0.6	99.4	<2.0	1.3	10.0	16.0	<0.1	481	253	0.01
Greene	Timbercrest MHP	7.3	260	<0.1	<0.02	12.8	1.5	91.0	25.6	1.5	28.0	38.0	0.11	381	333	0.03
Jasper	Sunset MHP	7.3	265	<0.1	<0.02	7.7	1.0	79.1	17.9	0.95	16.0	5.0	<0.1	312	271	0.01
Newton	Carefree MHP	7.0	240	<0.1	<0.02	5.4	0.5	90.6	<2.0	1.3	<10	9.0	<0.2	306	235	0.01

ALK - alkalinity Fe - iron Mn - manganese Na - sodium K - potassium Ca - calcium Mg - magnesium N - nitrogen
SO_4 - sulfate Cl - chloride F - fluoride TDS - total dissolved solids TH - total hardness Cu - copper

Table 16. Chemical analyses of selected Springfield Plateau small public water-supply wells. Analyses expressed in milligrams per liter (Missouri Department of Natural Resources, 1992.)

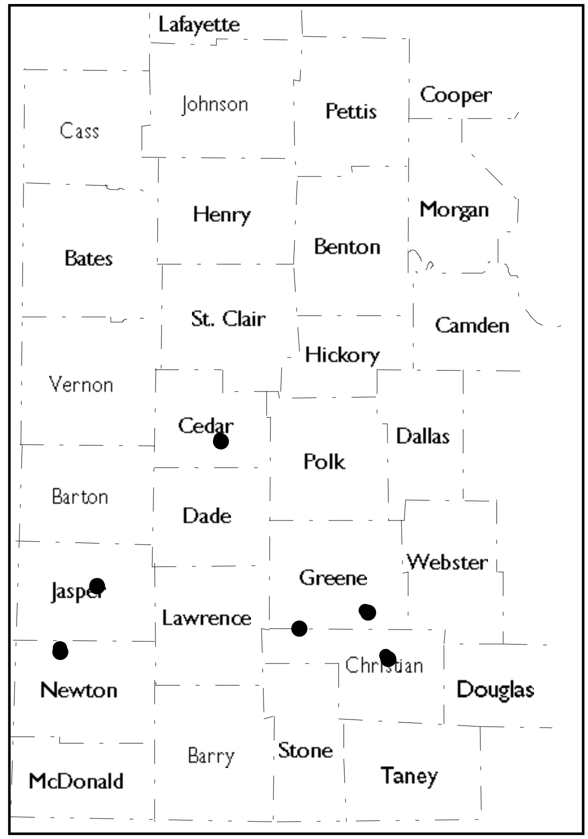


Figure 32. Approximate locations of selected Springfield Plateau small municipal water-supply wells.

water (Smith, 1988). Both publications are recommended for further detailed information.

Pesticides

Pesticides have been detected in wells and springs in the Springfield Plateau province. A recent study by the U.S. Geological Survey shows that sampled springs had higher incidence of pesticide detection than sampled wells, and more instances of detection in this province as compared to the adjoining Salem Plateau province (Adamski and Pugh, 1996). Agricultural land use in this province is high, particularly pasture land. Pesticides are commonly applied to pastures as well as row crops, thus higher concentrations of pesticides can exist at the surface to migrate down

into the groundwater. Table 17 lists important criteria about the wells and springs included in this study, and a listing of the pesticides detected and their general use. A summary of 1995 pesticide detections in municipal water-supply wells indicates that no public wells in this province had pesticide contamination (Missouri Department of Natural Resources, 1996). Reasons for this include the stringent well construction standards for public wells implemented by the Department of Natural Resources, and the fact that most public wells do not withdraw water from the shallow Mississippian formations that likely receive the highest concentration of pesticides.

NUTRIENTS

Nitrate and phosphate concentrations are generally below their respective maximum contaminant levels throughout the province. However, levels of nitrate are somewhat higher than in the adjoining Salem Plateau province, again probably due to application of agricultural chemicals such as fertilizers. Locally high values of both nitrate and phosphate may be found in the immediate vicinity of sewage treatment facilities, particularly if the discharge of the effluent is in a karst area. Nitrate and phosphate concentrations may also be elevated due to the proliferation of animal agriculture in this area. Concentrated animal feeding operations and land application

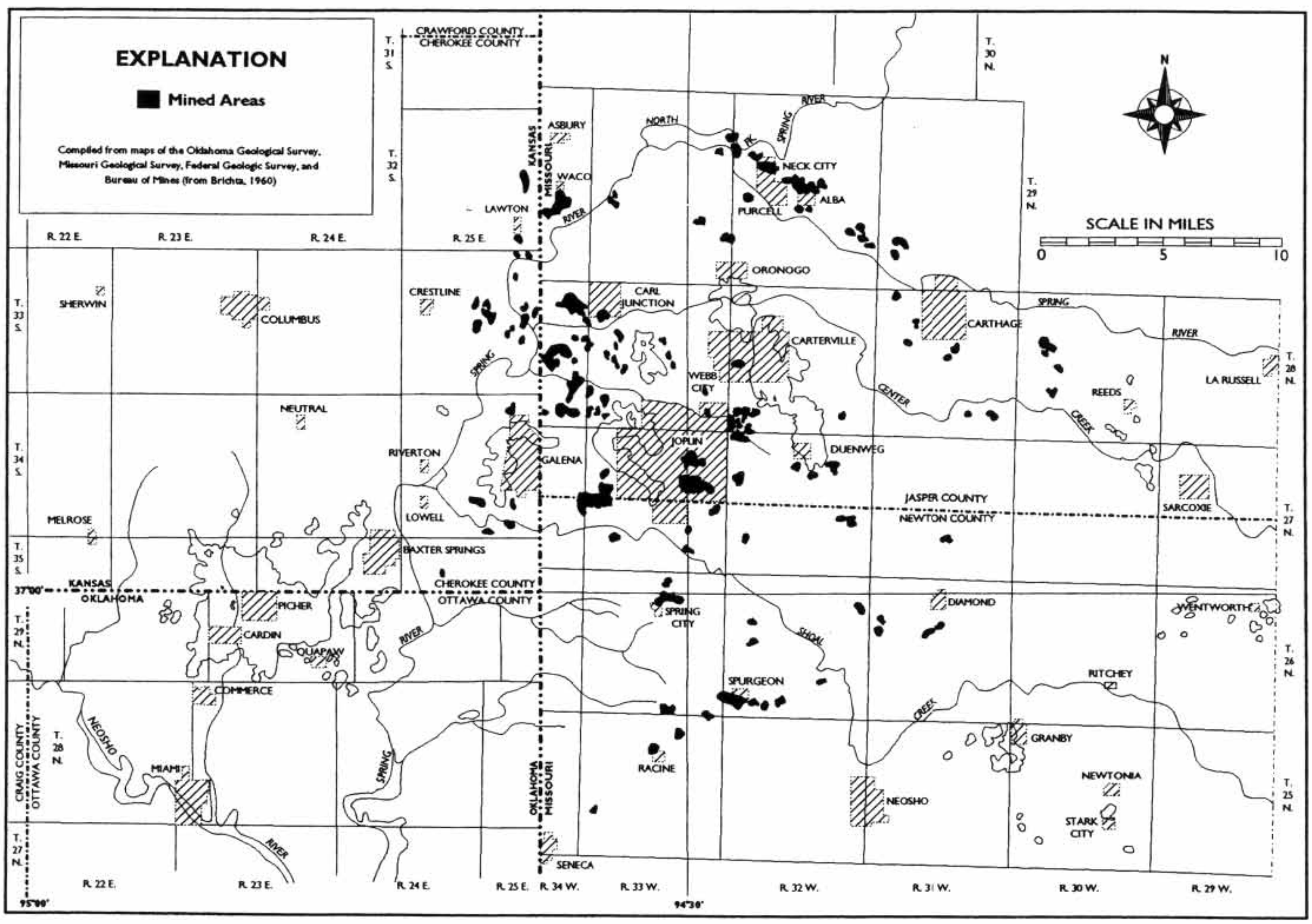


Figure 33. Principal part of the Tri-State Lead-Zinc District showing mined areas.

of animal manures as fertilizers are sources of the nitrate and phosphate.

Springs

Limestones present at the surface in the Springfield Plateau province provide excellent hosts for spring systems. While generally not as spectacular or large as those in the Salem Plateau, springs in this province are numerous. Recharge areas for these small springs often are contained within a single land use area, making contamination associated with land use very likely. A small recharge area makes for rapid contamination potential, but also rapid cleanup, and overall highly variable water quality. Water type is generally calcium bicarbonate, temperature ranges from 55^0 to 59^0 Fahrenheit, and total dissolved solids are generally 25 to 50 percent less than wells in the immediate area (Vineyard and Feder, 1982).

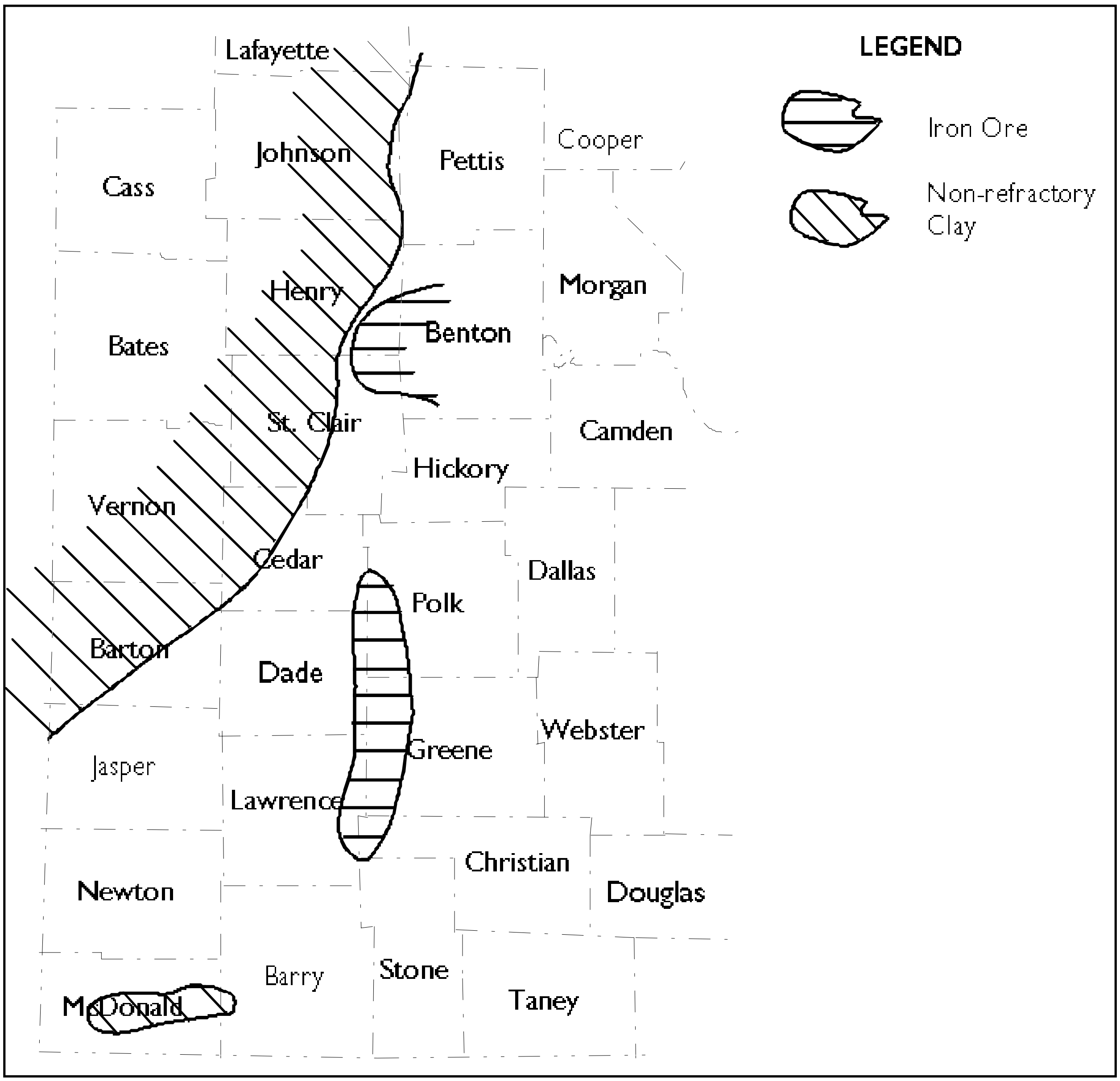


Figure 34. Iron ore deposits - Springfield Plateau groundwater province.

Springs with Detectable Pesticide Concentrations, Number of Pesticide Detections, Discharge, Aquifer, and General Land Use.
(L/min = liters per minute; CR = row-crop agriculture; F = forest; O = orchards; P = pasture; RC = residential/commercial; RR = rural residential; Springfield = Springfield Plateau Aquifer)

Local Identifier	Number of Pesticide Detections	Discharge (in L/min)	Aquifer	Percent Land Use in Basin					
				CR	F	O	P	RC	RR
+SP-1	1	117	Springfield	<5	33	<5	67	<5	<5
+SP-2	1	170	Springfield	<5	90	<5	10	<5	<5
+SP-4	1	511	Springfield	<5	67	<5	44	<5	<5
SP-5	3	1,090	Springfield	<5	20	<5	80	<5	<5
SP-6	2	390	Springfield	<5	10	<5	30	60	<5
SP-7	1	6,359	Springfield	<5	40	<5	60	<5	<5
+SP-8	1	560	Springfield	<5	90	<5	<5	<5	10
+SP-9	2	16,690	Springfield	10	50	<5	40	<5	<5
+SP-10	4	189	Springfield	<5	10	10	80	<5	<5
SP-11	1	379	Springfield	<5	40	<5	60	<5	<5
SP-14	2	1,885	Springfield	5	50	<5	45	<5	<5
+SP-19	1	719	Springfield	<5	40	<5	60	<5	<5

+ Springs not located in Missouri

Wells With Detectable Pesticide Concentrations, Number of Pesticide Detections, Depth, Aquifer, and General Land Use.
(m = depth, in meters below land surfaces; CR = row-crop agriculture; F = forest; P = pasture; RR = rural residential; - = depth unknown; Springfield = Springfield Plateau Aquifer)

Local Identifier	Number of Pesticide Detections	Depth (in m)	Aquifer	Percent Land Use Within 0.4 Kilometer Radius of Site			
				CR	F	P	RR
+SP-2	1	44	Springfield	<5	40	60	<5
+SP-8	1	—	Springfield	<5	90	10	<5
SP-15	1	—	Springfield	<5	<5	95	5
SP-16	3	122	Springfield	50	35	15	<5
SP-20	2	122	Springfield	<5	5	95	<5

+ Wells not located in Missouri

Pesticides Detected in Groundwater Samples Collected From Domestic Wells and Springs in the Ozark Plateaus Province.
(μg/L, micrograms per liter)

Pesticide	Number of Detections	Range of Concentrations (in μg/L)	General Use
Atrazine	14	0.001- 0.015	Selective and non-selective weed control
Prometon	11	.001- .13	Total vegetation control
Tebuthiuron	7	.005- .23	Total vegetation control
P,P' DDE	4	.002- .003	None (metabolite of DDT)
Metolachlor	3	.002- .003	Pre-emergent weed control in crop areas
Carbaryl	2	.012	Residential and crop insecticide
Chlorpyrifos	2	.003- .013	Residential and crop insecticide
Lindane	2	.028- .032	Crop insecticide
Propanil	2	.007- .012	Selective weed control in rice and wheat areas
Benfluralin	1	.003	Selective weed control in turf and crop areas
DCPA	1	.002	Pre-emergent weed control in crop and turf areas
Dieldrin	1	.025	Crop insecticide; no longer in use
Simazine	1	.011	Pre-emergent weed control in crops and turf areas
Trifluralin	1	.003	Pre- and post-emergent weed control in crop areas

Table 17. Salem Plateau wells and springs with pesticide detection. (Modified from Adamski and Pugh, 1996.)

OSAGE PLAINS

LOCATION AND GEOLOGY

The Osage Plains groundwater province comprises all or parts of nine counties in west-central Missouri (figure 35). Surface topography is generally flat-lying plains with some broad, rolling hills in its central part. The plains provide excellent areas for agricultural practices. Cattle and hogs are the principal livestock in the area, and corn, wheat, and soybeans are extensively row-cropped. Contaminants from both practices can affect shallow groundwater quality.

Sedimentary rocks that crop out at the surface are Pennsylvanian-age shales, sandstones and limestones. Formations included in this groundwater province are, in descending order, Kansas City Group, Pleasanton Group, Marmaton Group, and Cherokee Group. The Mississippian Burlington Limestone is also included in this groundwater province, as well as the underlying Cambrian-Ordovician formations previously discussed in the Salem and Springfield Plateau sections of this document. Table 18 shows approximate thicknesses and lithologic characteristics of each of these formations.

WATER TYPE

Groundwater in the Osage Plains groundwater province is primarily sodium-chloride type that may be classified as moderately saline. This is true when speaking specifically of the Pennsylvanian rocks at or near the surface. However, the Mississippian limestones below are generally sodium bicarbonate to sodium chloride. Possible leakage from the overlying Pennsylvanian rocks may account for the presence of the sodium chloride characteristics (Kleeschulte et al, 1985). The Cambro-Ordovician rocks at great depth in this province, generally contain water that is a sodium-chloride type.

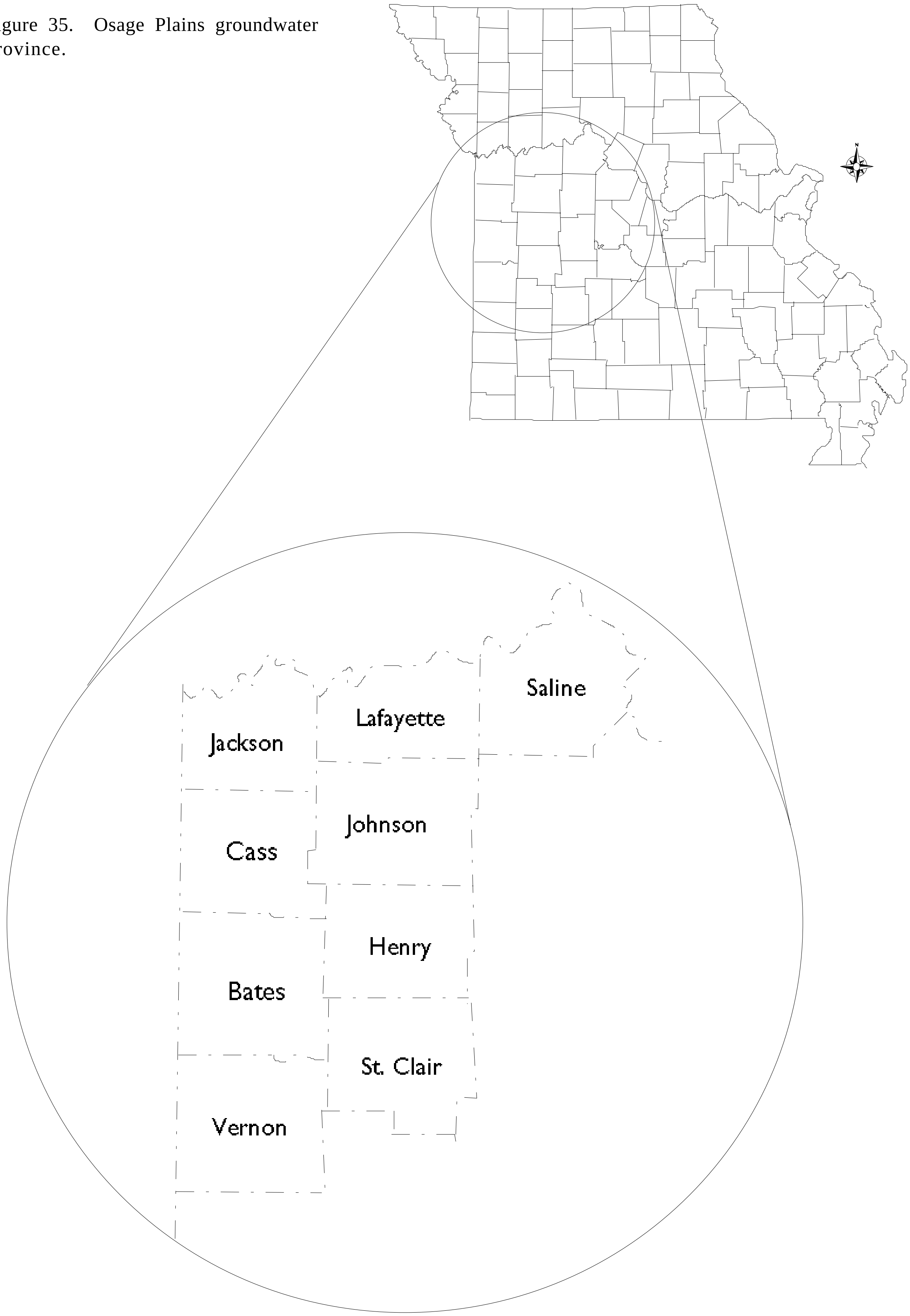
TOTAL DISSOLVED SOLIDS

Total dissolved solids, TDS, in this province range from approximately 330 mg/l to as much as 7,000 mg/l. The high variability of these values is based upon well location in proximity to the freshwater-salinewater interface and depth of completion of the well. High concentrations of sodium and chloride account for the high total dissolved solids. Table 19 lists chemical analyses for selected municipal water-supply wells utilizing this aquifer and figure 36 shows their locations.

SULFATE AND CHLORIDE

Concentrations of sulfate in the Osage Plains groundwater province vary greatly between different rock types and formations. There are insufficient data to show the areal distribution of sulfate and chloride in Pennsylvanian shales, however it is known that chloride is a predominant factor in the high TDS from this zone. Mississippian and Cambro-Ordovician formations were sampled in a 1985 study conducted in Barton, Vernon, and Bates counties. Vernon and Bates counties are in close proximity to the freshwater-salinewater interface in this province. Table 20 shows the chemical analyses of the wells sampled in those counties. From this data it appears that

Figure 35. Osage Plains groundwater province.



SYSTEM	SERIES	GEOLOGIC UNIT	THICKNESS (FEET)	LITHOLOGY
Pennsylvanian	Missourian	Kansas City	0-80	Thick alternating beds of shale, clay, and sandstone. Some massive ls
		Pleasanton Gr.	0-160	Sandstone, shale, limestone, dominantly clastic
		Marmaton Gr.	0-80	Interbedded cyclic ls, ss, sh with some coal beds
	Desmoinesian	Cherokee Gr.	0-400	Interbedded cyclic ls, ss, sh with some coal beds
Mississippian	Osagean	Burlington LS	80-230	Med to coarsely crystalline, med to thick bedded limestone
Dolo - dolomite Silt - siltstone Sh - shale Ss - sandstone Ls - limestone				

Table 18. Stratigraphy of Osage Plains groundwater province rocks (Howe, et al, 1961)

sulfate concentrations are similar in the Mississippian and Cambrian-Ordovician formations, and chloride values are greater in the Cambrian-Ordovician formations than in the shallower Mississippian rocks. Although this data is only available in two counties of the province, similar assumptions may apply to the remaining area. Due to poor groundwater quality in Cass, Johnson, Jackson, Lafayette, and Saline counties, sources other than groundwater are utilized for water supplies. Minimal usage of the groundwater may account for the lack of sufficient groundwater quality data.

Other Inorganics

Iron and manganese are prevalent constituents in groundwater from Pennsylvanian formations in this province. Values from 50 to 8,600 micrograms per liter (ug/l) iron and from 20 to 7,800 ug/l manganese were detected in water from shallow wells in Bates, Cass, St. Clair, and Vernon counties in 1991 (Ziegler et al, 1994). Eighty-seven percent of the wells sampled had iron concentrations above 100 ug/l, while 70 percent had manganese above 20 ug/l. Again, the deficit in water quality data in the northern counties of this province is due to alternate sources of water being utilized.

Pesticides

During 1990 and 1991, Zieglar and others conducted a study in the west-central Missouri counties of Bates, Cass, Vernon, and St. Clair. Shallow wells utilizing water from Pennsylvanian shales, siltstones, and sandstones were sampled and analyzed for pesticides. Of the 92 wells sampled during 1990, twenty-nine showed pesticide detection, but only three wells had concentrations above MCL. Atrazine was the most common pesticide detected. Additional sampling of 49 wells in 1991 indicated that 27 wells had pesticide contamination; twenty-six contained atrazine, but only one well had pesticide concentration above MCL. More pesticide detections were made in water originating from the Marmaton or Cherokee Groups of Pennsylvanian-age. The sandstones and siltstones from these groups have higher permeabilities than the shales of other formations, which allows for more movement of the pesticides in groundwater (Zieglar et al, 1994).

A summary of 1995 pesticide monitoring by the Missouri Department of Natural Resources shows that there were no public water-supply wells in this groundwater province that had pesticide detection (MDNR,DEQ, PDWP, 1996.)

Nutrients

The same wells described above were also sampled and analyzed for nitrate, dissolved ammonia, and orthophosphate. Twenty-four percent of wells sampled had nitrate concentrations equal to or exceeding the Missouri Safe Drinking Water Law maximum

contaminant level of 10 mg/l. From this data it appears that the larger diameter, shallower wells had the highest concentrations of nitrate. Also, proximity to agricultural chemical mixing areas and fertilized row crops increased the nitrate concentrations (Ziegler et al, 1994). A 1994 study determined that less than 10 percent of shallow bored and dug wells, some of which are in this province, showed nitrate contamination (Missouri Department of Health, 1994). Dissolved ammonia concentrations ranged from less than 0.01 to 0.86 mg/l, and orthophosphate concentrations were from less than 0.01 to 0.82 mg/l (Zieglar et al, 1994).

Springs

Due to the geologic setting throughout the Osage Plains groundwater province, springs are rare, and if present, generally have very small intermittent discharge. Groundwater flow along bedding planes might occur, and if conditions are prime, a small orifice in the rock might issue forth water in a spring-like manner.

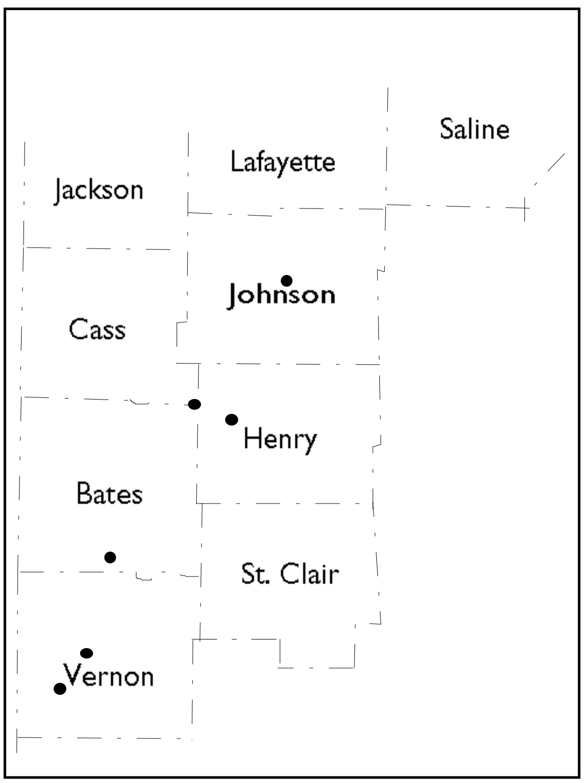


Figure 36. Approximate locations of selected Osage Plains municipal water-supply wells.

COUNTY	CITY	pH	ALK	Fe	Mn	Na	K	Ca	Mg	N	SO_4	Cl	F	TDS	TH	Cu
Bates	Rich Hill*	7.2	206	<0.1	0.03	452	17	96.3	42.7	<0.05	73.0	908	0.99	1955	416	0.10
Cass	Creighton*	7.7	432	0.2	<0.02	690	17	29.4	15.8	<0.05	23.0	863	2.78	1906	139	0.02
Henry	Urich	8.4	582	<0.1	<0.02	488	8.1	6.9	5.1	0.05	63.0	318	3.3	1175	38	0.01
Johnson	Warrensburg	7.8	202	<0.1	<0.02	40.9	4.1	49.4	23.3	<0.05	37.0	53	0.68	336	219	0.03
Vernon	Nevada*	8.2	74	<0.1	<0.02	113	3.5	16.8	9.7	<0.05	20.0	183	0.99	386	82	<0.01
Vernon	PWSD #1	7.9	536	<0.1	<0.02	344	9.2	37.9	20.2	<0.05	33.0	312	2.32	1197	178	0.01

ALK - alkalinity Fe - iron Mn - manganese Na - sodium K - potassium Ca - calcium Mg - magnesium N - nitrogen SO_4 - sulfate Cl - chloride F - fluoride TDS - total dissolved solids TH - total hardness Cu - copper

* Finished water has been treated for iron and/or hydrogen sulfide reduction

Table 19. Chemical analyses of selected Osage Plains municipal water-supply wells. Analyses expressed in milligrams per liter (Missouri Dept of Natural Resources, 1992)

Water-quality data for wells in Vernon and Bates Counties, 1982
(μmhos, micromhos per centimeter at 25° Celsius; °C = degrees Celsius; mg/l = milligrams per liter; < = less than)

Location	Date of Samples	Specific conductance (μmhos)	pH (units)	Temperature (°C)	Calcium, dissolved (mg/l as Ca)	Magnesium, dissolved (mg/l as Mg)	Sodium, dissolved (mg/l as Na)	Sodium adsorption ratio	Potassium, dissolved (mg/l as K)	Bicarbonate (mg/l as HCO_3)	Sulfate, dissolved (mg/l as SO_4)	Chloride, dissolved (mg/l as Cl)	Solids residue at 180°C dissolved (mg/l)
Vernon County													
T.34N., R.29W., 6aaa1[1]	82-9-23	595	7.6	17.0	37	20	67	2.4	5.8	318	44	16	318
T.34N., R.30W., 25bcd1[1]	82-7-23	942	7.5	17.0	85	44	56	1.4	5.0	317	250	7.9	629
T.34N., R.31W., 11ada1[1]	82-7-30	1,400	7.9	17.5	6.6	2.8	340	31	5.8	806	5.0	83	852
T.34N., R.31W., 35ada3[2]	82-7-23	810	7.8	20.0	42	18	97	3.4	4.1	218	22	150	435
T.34N., R.32W., 5aaa1[2]	82-9-22	1,970	7.8	18.5	39	19	390	13	8.6	746	40	290	1,070
T.34N., R.32W., 20baa1[2]	82-7-22	2,080	7.5	21.0	75	33	310	7.5	9.0	324	69	510	1,160
T.35N., R.30W., 32bab1[1]	82-7-30	990	8.0	18.0	8.4	4.2	260	20	5.8	630	20	62	683
T.35N., R.31W., 5dba1[2]	82-7-29	2,270	7.5	20.0	77	38	330	7.7	9.8	274	75	580	1,310
T.35N., R31W., 13abc1[2]	82-7-30	1,775	7.6	19.0	61	31	250	7.2	8.0	260	54	430	1,020
T.35N., R.31W., 20bdc1[1]	82-9-23	1,240	7.9	16.0	0.4	0.1	330	129	.9	754	<5.0	58	774
T.35N., R.32W., 17acb1[1]	82-7-29	2,300	7.6	18.5	12	9.8	550	29	9.4	1,158	17	220	1,410
T.36N., R.29W., 7dbd1[2]	82-7-28	1,200	7.6	20.0	53	24	160	5.0	6.6	226	35	260	606
T.36N., R.29W., 9baa1[2]	82-7-28	1,105	7.6	18.0	50	24	140	4.5	6.1	226	34	230	594
T.36N., R.29W., 17cdd1[1]	82-7-28	1,110	7.6	20.0	44	22	140	4.7	6.3	238	28	230	590
T.36N., R.30W., 15 bcc1[2]	82-7-28	1,350	7.6	20.0	57	27	210	6.3	7.5	242	41	340	816
T.36N., R.31W., 33bcb1[2]	82-7-29	2,300	7.4	19.5	81	40	330	7.5	10	270	73	580	1,330
T.36N., R.31W., 36cba1[1]	82-7-27	1,650	7.6	21.5	.9	.0	430	123	2.5	814	<5.0	180	1,030
T.36N., R.32W., 1aca1[2]	82-7-27	2,150	7.8	19.5	82	39	360	8.2	11	276	71	640	1,370
T.36N., R.32W., 3caa1[2]	82-7-27	2,340	7.5	19.0	76	36	360	8.5	11	308	68	600	1,320
T.36N., R.32W., 4cca1[2]	82-7-26	2,225	7.4	19.5	77	37	370	8.7	11	298	74	660	1,410
T.36N., R.32W., 7dbd1[2]	82-7-27	2,340	7.5	19.5	82	39	380	8.7	12	290	76	690	1,460
T.36N., R.32W., 22dbc1[2]	82-7-27	2,125	7.8	20.0	74	36	350	8.3	11	294	68	600	1,310
T.36N., R.32W., 30aca1[2]	82-7-27	3,150	7.2	18.5	55	30	610	16	13	774	36	750	1,800
T.37N., R.29W., 8dcb1[2]	82-7-27	1,430	7.7	20.5	50	24	200	6.4	7.5	246	39	320	784
T.37N., R.30W., 10cdc1[2]	82-7-27	1,730	7.9	21.0	—	—	—	—	—	268	—	—	—
T.37N., R.30W., 23dda1[1]	82-7-28	2,190	6.7	17.5	150	89	230	3.7	11	348	720	200	1,670
T.37N., R.31W., 17dbd1[2]	82-7-26	2,440	7.4	19.0	76	37	370	8.7	11	274	75	620	1,400
T.37N., R.31W., 36abd1[2]	82-7-27	1,840	7.5	21.0	69	34	300	7.4	9.6	286	62	520	1,150
T.37N., R.32W., 15aac1[2]	82-7-26	2,590	7.4	19.5	87	41	400	8.9	12	288	74	720	1,510
T.37N., R.32W., 16bad1[2]	82-7-26	2,650	7.4	20.0	85	41	410	9.1	12	288	78	750	1,540
T.37N., R.32W., 32bac1[2]	82-7-21	2,430	7.4	19.5	86	41	420	9.3	12	300	78	740	1,560
T.38N., R.29W., 33ddd1[2]	82-7-28	1,510	7.5	19.0	53	25	220	6.9	7.8	242	37	340	797
T.38N., R.32W., 29aad1[1]	82-7-28	2,850	7.5	20.5	64	35	490	12	12	344	77	780	1,620
Bates County													
T.38N., R.29W., 18ccd1[1]	82-9-22	2,330	7.7	16.5	58	31	380	10	11	270	53	610	1,230
T.38N., R.30W., 3dad1[1]	82-9-22	3,375	7.3	18.0	92	43	580	13	13	294	85	1,000	1,880
T.38N., R.31W., 18dba1[1]	82-9-22	2,570	7.8	18.0	60	29	480	13	11	512	61	610	1,450
T.38N., R.31W., 20cdb1[1]	82-9-22	1,390	8.3	16.0	9.5	4.4	340	25	7.2	908	8.0	52	875
T.38N., R.32W., 16dcc1[1]	82-9-21	3,525	7.5	19.0	81	40	600	14	13	382	80	1,000	1,850
T.39N., R.29W., 29ccd1[2]	82-9-22	3,900	7.5	18.5	89	42	700	15	14	300	84	1,200	2,160
T.39N., R.32W., 31aba1[1]	82-9-21	7,500	8.1	16.0	42	22	1,600	50	21	736	28	2,300	4,150
T.39N., R.33W., 15bcc1[1]	82-9-21	5,000	8.0	16.0	17	14	1,200	52	10	1,300	16	1,200	2,960
T.41N., R.32W., 15ccd1[3]	82-9-21	820	7.8	21.0	60	30	76	2.2	1.6	368	110	13	440

[1] Well primarily open to the Mississippian aquifer
[2] Well primarily open to the Cambrian-Ordovician aquifer
[3] Sample was treated before collection and is not discussed in text or maps

Table 20. Chemical analyses of wells in Vernon and Bates counties, Osage Plains groundwater province (modified from Kleeschulte, et al, 1985)

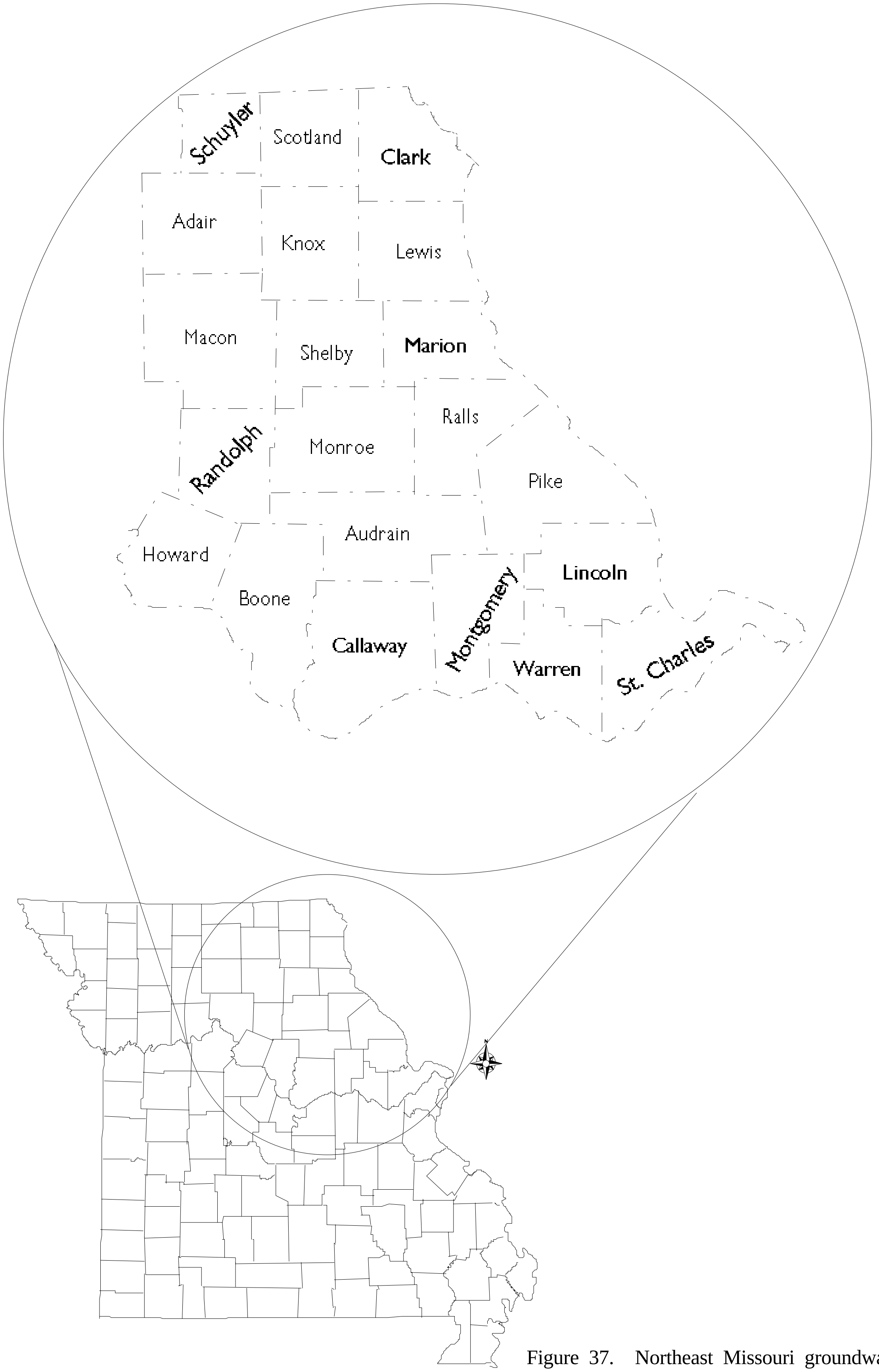


Figure 37. Northeast Missouri groundwater province.

NORTHEAST MISSOURI

LOCATION AND GEOLOGY

The Northeast Missouri groundwater province comprises all or parts of 21 counties in the extreme northeastern portion of the state (figure 37). Sedimentary rocks of Pennsylvanian shales and sandstones and Mississippian limestones make up most of the surface geology, however a northwest-trending band of Ordovician rocks appear at the surface in eastern Ralls and Pike counties. Boone, Audrain, Pike, Lincoln, St. Charles, Warren, Montgomery, and Callaway counties near the southern boundary of this province are quite similar in geologic and hydrologic composition to the Salem Plateau groundwater province. Refer to that discussion for characterization of these counties. The geologic units included in the Northeast Missouri groundwater province are, in descending order, loess, glacial till or drift, Pleasanton Group, Marmaton Group, Cherokee Group, Krebs Subgroup, St. Louis Limestone, Salem Formation, Warsaw Formation, Keokuk Limestone, and Burlington Limestone. Below these formations lie the previously defined rocks included in the Salem Plateau groundwater province discussion. Table 21 lists the stratigraphic relationships and lithologic characteristics of these rock formations.

At the end of glaciation in Missouri, previously dissected Pennsylvanian rocks in northern Missouri were scoured by retreating ice sheets. The result is a combination of pre-glacial and post-glacial erosional surfaces. Glacial drift deposited in previous erosional valleys can be quite thick, up to several hundred feet. However, the drift appears to thin to a mere 50 feet or less in the southern part of the province. Pennsylvanian sandstones and shales and Mississippian limestones provide the area with extensive plains and gently rolling hills. These conditions encourage livestock production and extensive agricultural crops, particularly corn, soybeans, hay, wheat, and sorghum.

GROUNDWATER QUALITY

WATER TYPE

Water type in the Northeast Missouri groundwater province varies with location and geologic formation in which the water resides and can rapidly change between locations (Miller et al, 1994). Water type in the glacial drift generally is a mixture of calcium carbonate, calcium sulfate, and sodium sulfate. Pennsylvanian sandstones and shales contain water that is sodium chloride, sodium sulfate, calcium chloride, or calcium sulfate types. Mississippian limestones are mixed calcium bicarbonate - sodium chloride types depending upon depth of the limestones, and Ordovician dolomites at depth are calcium-magnesium bicarbonate to sodium chloride type (Missouri Division of Geological Survey and Water Resources, 1967).

TOTAL DISSOLVED SOLIDS

Total dissolved solids increase with depth in this province. Total dissolved solids in areas containing deposits of glacial drift can be quite high, ranging from approximately 300 to 3,000 mg/l (Miller et al, 1994). Pennsylvanian formations yield water with TDS ranging from 1000 to 2,000 mg/l. Mississippian formations have TDS ranging from 400 to 500 mg/l where

SYSTEM	SERIES UNIT	GEOLOGIC (FEET)	THICKNESS	LITHOLOGY
Quaternary	Pleistocene	Loess	0-40	Windblown silt
		Glacial Till or Drift	0-399	Silt, clay, sand, gravel, and boulders. May be bedded or indeterminant mixture. Deposited by melting glaciers.
Pennsylvanian	Missourian	Pleasanton Group	20-150 (90 avg)	Clastic sediments, shale, siltstone and scattered sandstone
	Desmoinesian	Marmaton Gr.	0-130	Shale, limestone, clay, and coal beds
		Cherokee Group	0-200	Sandstone, siltstone, shale, underclay, coal and thin limestone; cyclic
		Krebs Subgroup	0-110	Sandstone, siltstone, shale, clay limestone.Locally coal and conglomerate
Mississippian	Meramecian	St. Louis LS	<50	Fine to med crystalline limestone and shale
		Salem Formation	20-40	Buff colored limestone, dolomitic limestone, and shale
		Warsaw FM	40	Fine to coarsely crystalline limestone
	Osagian	Keokuk Limestone	60-70	Bluish gray, med to coarsely crystalline, med bedded limestone
		Burlington Limestone	20-100	White to tan coarsely crystalline, fossiliferous ls with chert nodules
Ls - limestone Dolo - dolomite Silt - siltstone Sh - shale Ss - sandstone				

Table 21. Stratigraphy of Northeast Missouri Groundwater Province rocks. Descriptions after Thompson 1986 and Howe, et al, 1961.

the limestones are at the surface, to as much as 17,000 mg/l where they are at depth. Ordovician formations at depth contain as much as 30,000 mg/l TDS (Missouri Division of Geological Survey and Water Resources, 1967). Shallow domestic wells completed in Pennsylvanian sandstones or glacial drift usually yield enough water moderately low in dissolved solids to satisfy domestic uses. Conversely, cities or industries requiring high yields often choose surface-water sources instead of the high-yielding, deeper mineralized formations.

Sulfate and Chloride

Concentrations of sulfate in the glacial drift deposits of this province range from 25 to 1,500 mg/l. Pennsylvanian, Mississippian, and Ordovician formations at depth generally contain water that has moderately higher sulfate concentrations, ranging from 250 to 3,000 mg/l. Chloride is present in low concentrations in the glacial drift, averaging 2 to 150 mg/l. However, the other formations contain large amounts of chloride, approximately 500 to as much as 22,000 mg/l with increasing depth.

Other Inorganics

Iron and manganese are quite prevalent in water from glacial drift deposits. Data, though insufficient to delineate areal distribution of these constituents, indicates that concentrations are higher in the glacial drift than the other formations. Of 47 glacial drift wells sampled during a 1992 study by Wilkinson and Maley, 30 percent had iron concentrations above Missouri Safe Drinking Water Law secondary (aesthetic) standard of 0.3 mg/l. Iron concentrations ranged from less than 0.05 mg/l to 22.1 mg/l. Likewise, 34 percent of these wells had concentrations of manganese exceeding the secondary standard of 0.05 mg/l, with values ranging from less than 0.02 mg/l to 3.02 mg/l (Wilkinson and Maley, 1994). Values ten times the secondary standards and higher generally are an aesthetic nuisance more than a health risk.

Pesticides

Herbicides were detected in a few shallow wells in northeastern Missouri during a 1992 study (Wilkison and Maley, 1994). One hundred forty-seven wells in Audrain, Clark, Lewis, Monroe, Scotland, and Shelby counties were sampled and analyzed for herbicides (figure 38). Nineteen of these wells had herbicide detection. All but one well contained atrazine, and only one had concentrations above MCL. While only 21 percent of the wells were completed in the Pennsylvanian- age Cherokee Group, samples from them comprised 60 percent of the detectable concentrations. Well depths ranged from 12 to 220 feet, and in diameter from 1.5 to 144 inches. From this data it can be generalized that the shallower, larger diameter wells used for domestic water-supplies are more susceptible to herbicide contamination. Sources of herbicide contamination may be point sources, such as mixing points or spills near wells, or nonpoint such as application to a field and subsequent infiltration to the groundwater.

Nutrients

The same study described above also yielded results of sampling for nitrate plus nitrite. Nineteen percent of wells sampled had concentrations of nitrate plus nitrite above the maximum contaminant level of 10 mg/l. Similarly, these results suggest that shallow, large diameter domestic use wells have the most potential for nitrate contamination. Common sources for nitrate are fertilizers, both mixing points and field applications, and wastes from animal feedlots or household septic systems.

Springs

The geological formations present at the surface in the Northeast Missouri groundwater province are mostly glacial till, shales, and dense sandstones and limestones. Springs in this area are few and where they do exist have low, intermittent flow.

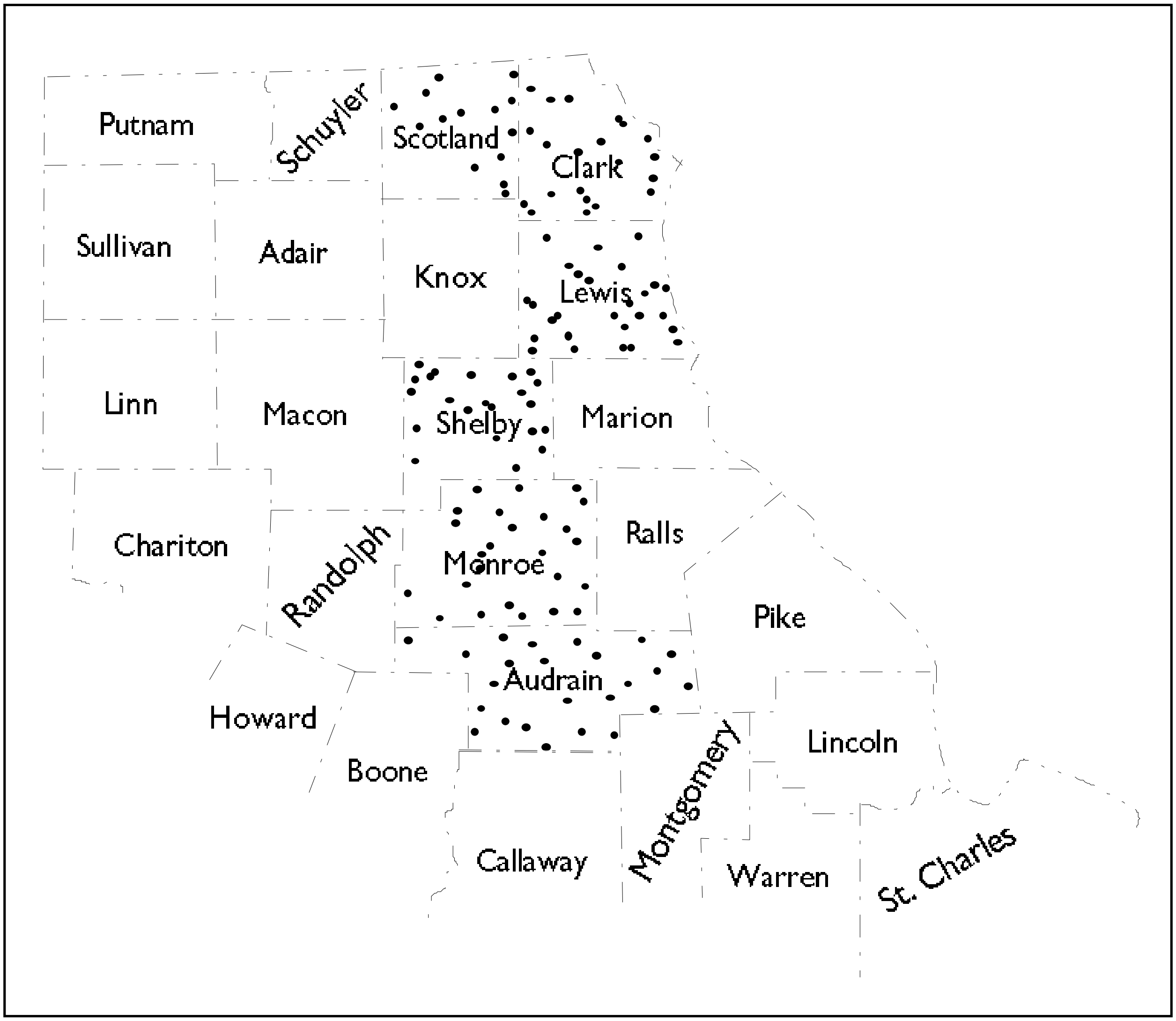


Figure 38. Approximate locations of wells sampled for pesticides, Northeast Missouri groundwater province.

NORTHWEST MISSOURI

LOCATION AND GEOLOGY

The Northwest Missouri groundwater province comprises all or parts of 23 counties in the extreme northern part of the state (figure 39). Sedimentary rocks occurring at the surface are varied, including glacial deposits, sandstone, shale, and limestone. Geologic rock formations in this province are, in descending order, loess, glacial till or drift, preglacial deposits, Wabaunsee Group, Shawnee Group, Douglas Group, Pedee Group, Lansing Group, Kansas City Group, Pleasanton Group, Marmaton Group, and Cherokee Group. Geologic formations below these units yield water too mineralized for consumption in this province and will not be included in its discussion. Table 22 lists stratigraphic location and lithologic characteristics for each formation.

Glacial deposits composed of sand, silt, clay, gravel, and boulders overlie Pennsylvanian shales, limestones, and sandstones in much of the province. The glacial till may be very thin to quite thick, nearly 400 feet thick in the extreme northwestern part of the province. Preglacial channel deposits underlie the glacial till in many areas and may reach thicknesses greater than 100 feet (figure 40). Where the glacial till is absent, Pennsylvanian formations appear at the surface. Both the glacial till and the Pennsylvanian rocks provide vast flat-lying topography disturbed only by a few rolling hills. This, coupled with numerous mature floodplains, allows the area to be one of the most productive agricultural regions in the state.

GROUNDWATER QUALITY

WATER TYPE

Groundwater type in the Northwest Missouri groundwater province varies greatly depending upon geologic formation and thickness. Water from the glacial deposits can be calcium carbonate, calcium sulfate, or sodium sulfate type (Miller et al, 1994). Preglacial channel deposits typically are similar in type to the glacial deposits. Shallow Pennsylvanian sandstones, limestones, and shales contain water that ranges from calcium chloride to sodium chloride. Where these units are at depth, the water type is generally calcium sulfate to sodium sulfate.

TOTAL DISSOLVED SOLIDS

Total dissolved solids in water from glacial till ranges from 400 to 1,500 mg/l. Preglacial channel deposits generally have higher concentrations of dissolved solids making the water less desirable than that from the till. Where the Pennsylvanian formations are at the surface or fairly shallow, TDS ranges from 800 to 2,000 mg/l. At greater depths, the TDS increase from 2,000 to as much as 20,000 mg/l. Table 23 shows historical chemical analyses for selected wells in the province. Note that the wells are completed to different total depths, and that even the shallowest well has a high concentration of dissolved solids.

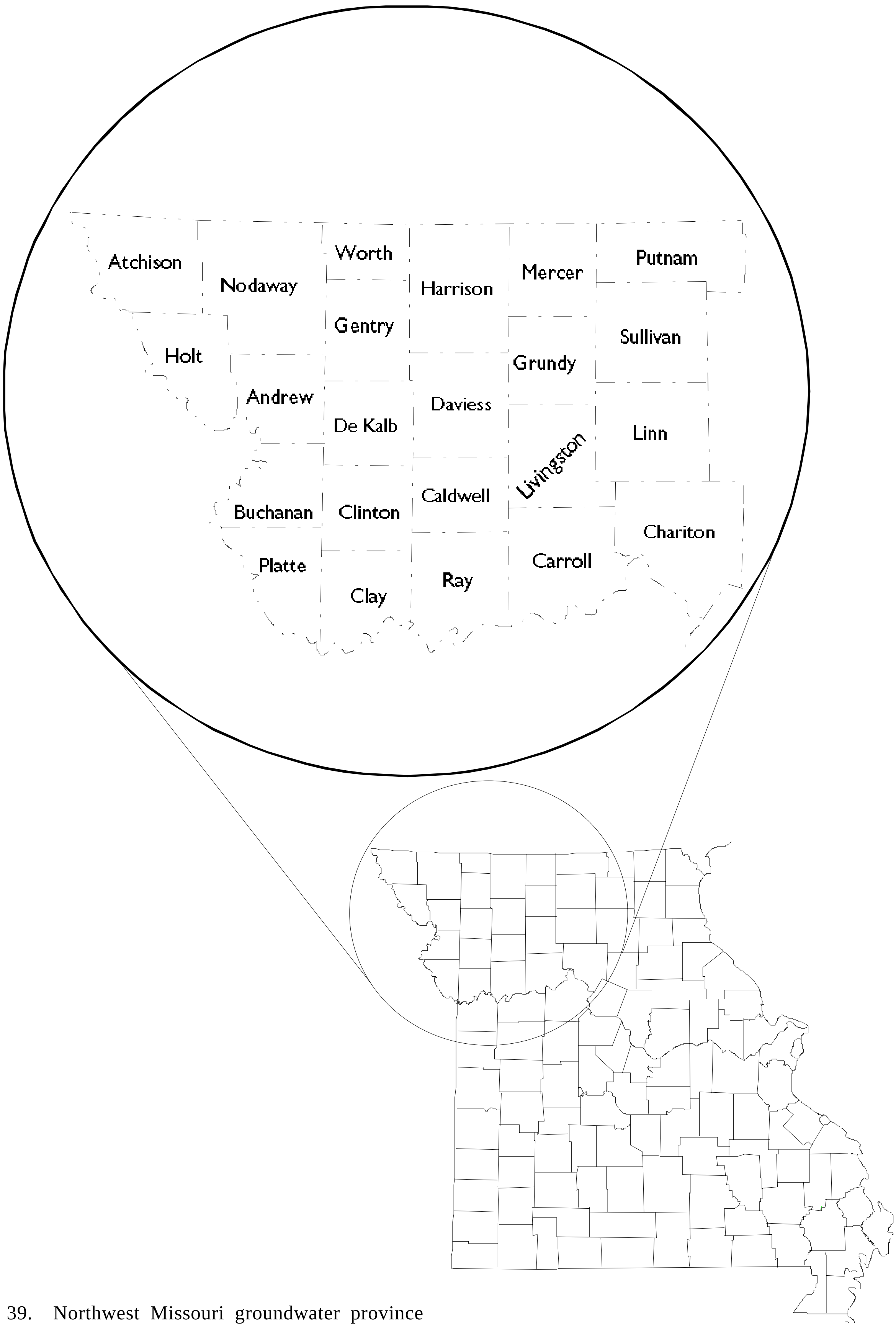


Figure 39. Northwest Missouri groundwater province

SYSTEM	SERIES	GEOLOGIC UNIT	THICKNESS (FEET)	LITHOLOGY
Quaternary	Pleistocene	Loess	0-40	Windblown silt
		Glacial Till or Drift	0-399	Silt, clay, sand, gravel, and boulders. May be bedded or indeterminant mixture. Deposited by melting glaciers.
Pennsylvanian	Virgilian	Preglacial fill	0->100	Sand and gravel, silt and clay intermixed
		Wabaunsee Gr.	0-340	Shale, siltstone, and sandstone
		Shawnee Group	230-250	Thick limestone with intervening shale beds
		Douglas Group	110-150	Predominantly clastic shales, sandstone, and thin limestone
	Missourian	Pedee Group	60-100	Thick sequence of shale with lime at the top
		Lansing Group	60	Thick limestone sequences separated by shale and sandstone
		Kansas City Group	50-310	Thick limestone with intervening shale, sandstone, shale in lower part
		Pleasanton Group	20-150 (90 avg)	Clastic sediments, shale, siltstone and scattered sandstone
	Desmoinesian	Marmaton Group	0-130	Shale, limestone, clay, and coal beds
		Cherokee Group	0-200	Sandstone, siltstone, shale, underclay, coal and thin limestone; cyclic
Ls - limestone Dolo - dolomite Silt - siltstone Sh - shale Ss - sandstone				

Table 22 - Stratigraphy of Northwest Missouri groundwater province rocks. Descriptions after Howe, et al, 1961.

Sulfate and Chloride

Widely variable concentrations of sulfate and chloride in this province makes interpretation of areal distribution difficult. Generally, sulfate concentrations in the glacial till range from 20 to 1,400 mg/l and values of 250 to 3,000 mg/l are typical in the other formations. Chloride concentrations for water from the glacial till are the lowest for any water-producing zone in this province. Typical values are 2 to 150 mg/l. Water from deeper zones contains chloride in concentrations from 500 to 22,000 mg/l.

Other Inorganics

Iron and manganese are prevalent constituents in water from glacial till and preglacial deposits. Concentrations vary widely and areal distribution of these constituents is difficult. General values for iron range from 0.4 to 18.0 mg/l (0.3 mg/l is MCL). Manganese concentrations typically range from 0.3 to 1.8 mg/l (0.05 mg/l is MCL). Treatment for removal of these constituents is common if the water is used for human consumption. A 1991 study of 130 rural domestic wells by the U.S. Geological Survey showed iron concentrations great-

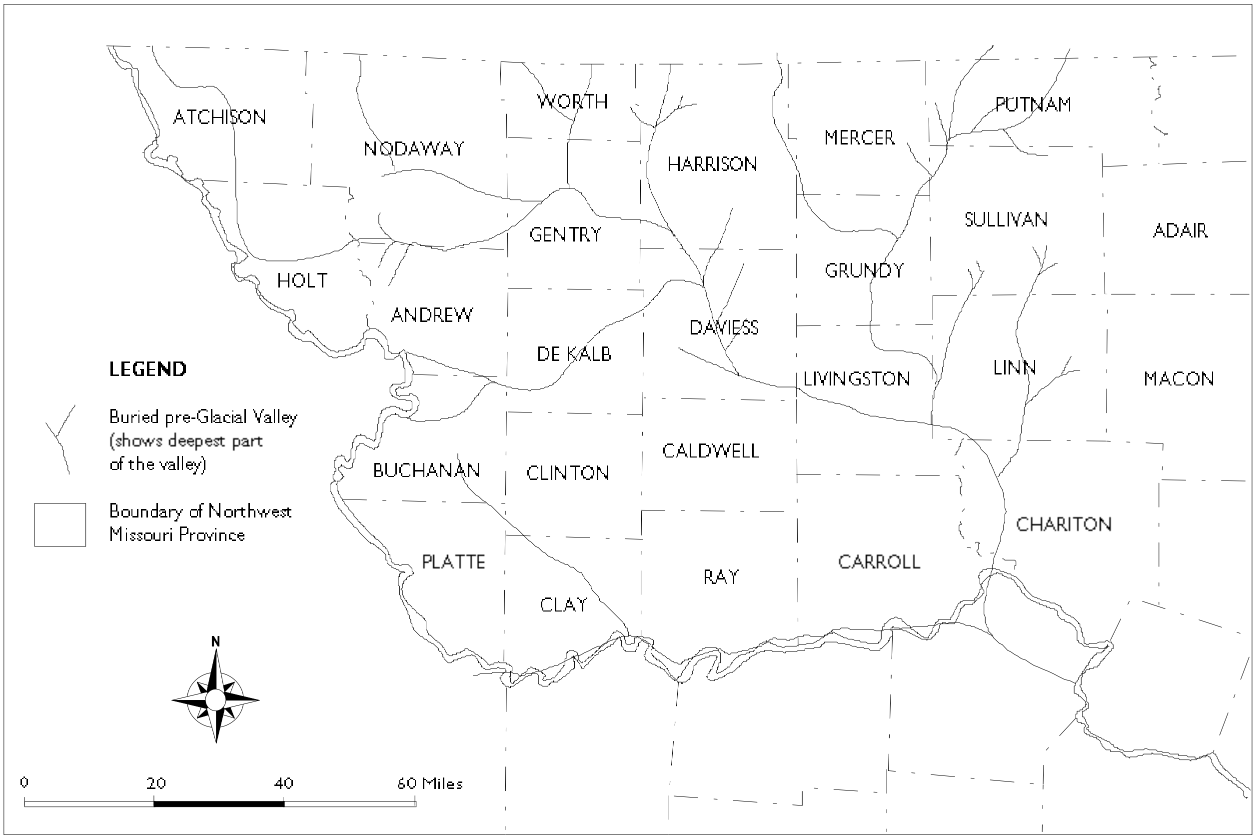


Figure 40. Pre-glacial channels - Northwest Missouri groundwater province (from Gann and others, 1973).

er than 0.5 mg/l in 18 percent of the wells, and manganese greater than 0.05 mg/l in 29 percent of the wells. Figure 41 shows the approximate locations of the wells involved in the project.

Pesticides

Pesticides were analyzed in water samples from 130 rural domestic wells in Caldwell, Clinton, Daviess, Gentry, and Nodaway counties in 1991. Pesticides were detected in 19 of the wells and atrazine in 16 of the 19 wells, though above the maximum contaminant level in only one well. Shallow large diameter wells had more detections of pesticides than deeper, small diameter wells (Wilkison and Maley, 1994). Refer to figure 41 for approximate well locations.

Nutrients

The study described above also showed instances of nitrate plus nitrite contamination in shallow, large diameter domestic wells. Twenty-four percent of the wells sampled had concentrations equal to or greater than the maximum contaminant level of 10 mg/l. Proximity to fertilizer mixing sites, land application, animal feedlots, and septic systems probably increased the instances of nitrate contamination (Wilkison and Maley, 1994).

Springs

Northwestern Missouri has numerous small springs that issue from the Pennsylvanian to Ordovician rocks. Generally, the flow is small and the quality of the water marginal, usually saline.

COUNTY	SUPPLY	DEPTH	pH	ALK	Fe	Mn	Na	K	Ca	Mg	N	SO_4	Cl	F	TDS	TH	Cu
Andrew	Ralph Eckles	189	7.6	—	0.3	0.00	607	—	76	30	—	396	502	1.4	1817	—	—
Atchison	Tarkio	—	8.8	224	1.88		226		96.4	37.0		49.5	100	0.4	1326	393	
Buchanan	Bethany Falls Stone	384	288				3607	65	31		5.1	5402			9793	289	
Carroll	Rudolph Kruse	495			3.4	0.05	3324		322	158		1073	5000	1.4	10277		
Chariton	NW School	42	6.8	217.5	0.34	0.75	42		59.4	11.9		24.9	3.8	0.3	307	197	
Daviess	Pattonsburg School	60.5	6.0	46	1.0		24.2		65.6	14.4		153	31.6	0.1	405		
Dekalb	Hugh Swords	425	8.2		3.8	0.17	1632		96	47		216	2348	0.6	4589		
Gentry	Slagle Farms	1600	7.0	313	0.03		1708		66.5	30.4		1389	1652		5091	291	
Grundy	CMPP Railroad	416		502.1		0.03	2406		35.7	18.9		1128	2550	1.5	6781	167	
Harrison	Ridgeway	1178	7.3		1.5	0.00	1500	35	94	30		1704	1150	1.8	4914		
Linn	R.E. Dolan	565	7.6		3.4	0.05	2397		84	46		988	3060	1.4	678		
Mercer	Public School	450	7.9		2.7	0.00	744		41	29		313	278	1.6	2011		
Nodaway	Greys Service	?Glac.	7.1	280	0.13	0.53	1365		270	80.5		927	15.3	0.00	1779	1005	
Platte	John Gaskill	460	7.6		30.0		3757		84	40		39	5747		9768		
Sullivan	Humphreys Sch.	165	7.1	231.5	6.8	0.91	410		448	160		2179	16.3	0.9	3558	1774	
Worth	MO Geol. Sur.		7.5	200.5	0.46	0.0	388.3		111.5	32.5		945.3	50.3				

ALK - alkalinity Fe - iron Mn - manganese Na - sodium K - potassium Ca - calcium Mg - magnesium N - nitrogen
SO_4 - sulfate Cl - chloride F - fluoride TDS - total dissolved solids TH - total hardness Cu - copper

Table 23. Historic chemical analyses of Northwest Missouri groundwater province wells. Data from series of county water resource possibilities, Missouri Geological Survey, 1957.

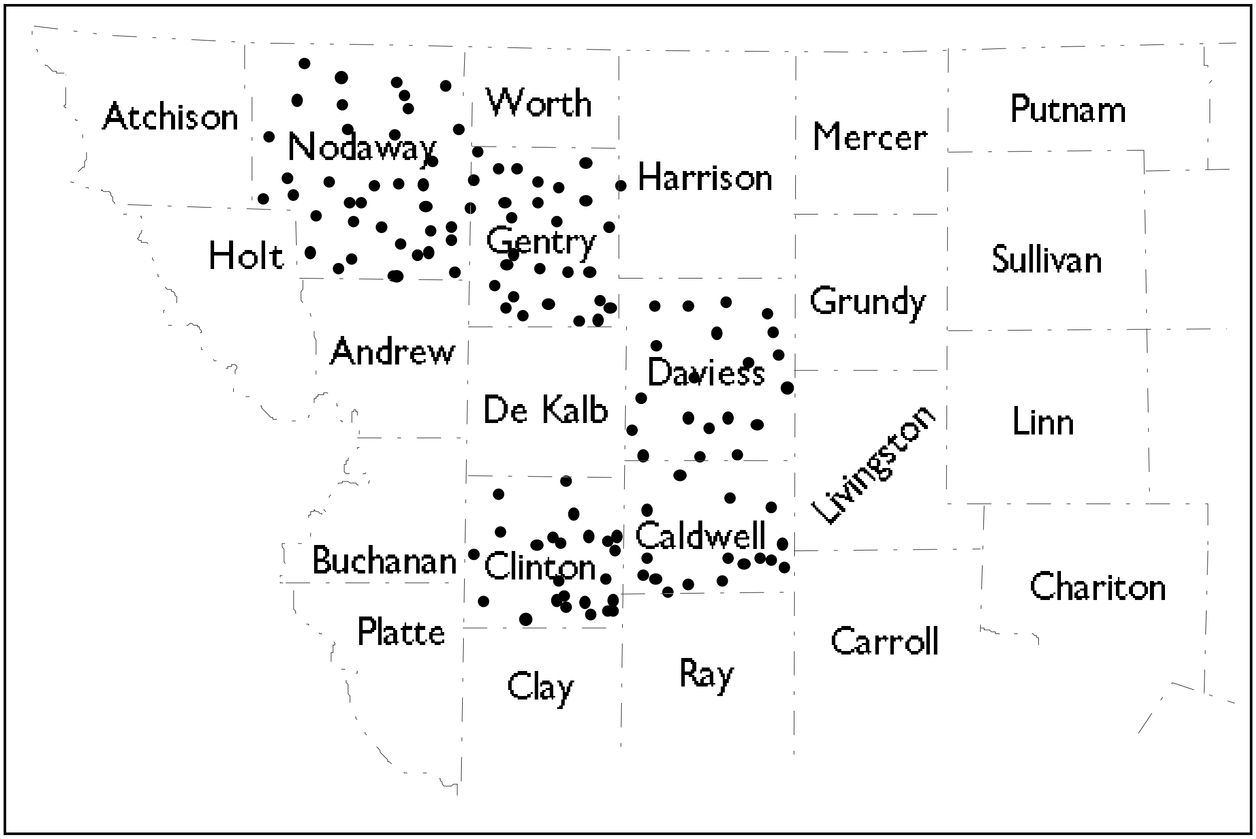


Figure 41. Approximate locations of wells sampled for pesticides, Northwest Missouri groundwater province.

SOUTHEAST MISSOURI

LOCATION AND GEOLOGY

The Southeast Missouri groundwater province comprises all or parts of 11 counties in the extreme southeastern part of the state (figure 42). It is the area routinely referred to as the "Bootheel." The Bootheel covers about 4,000 square miles and is the northern extension of the Mississippi Embayment physiographic province in the southeastern United States. The topography is a series of lowlands adjacent to each other that are occasionally separated by small ridges and hills. These northeast to southwest-trending ridges are erosional remnants of earlier plains. Located as much as 250 feet higher than the surrounding lowlands, these ridges are commonly called Crowleys Ridge, Hickory Ridge, and Benton Hills (figure 43). Historically, the Bootheel area was covered by wetlands, but extensive draining and clearing has made it one of the most intensively developed agricultural areas in Missouri.

Sedimentary deposits included in this groundwater province are, in descending order, alluvium, loess, Wilcox Group, Midway Group (Porter Creek Clay and Clayton Formation), and McNairy (Ripley) Formation. Beneath these formations lie the Paleozoic carbonates included in the Salem Plateau groundwater province. Except in the western part of the embayment, these rocks contain water that has marginal to poor quality. This fact, in addition to the availability of water at lesser depths, deters communities from utilizing the Paleozoic carbonate rocks as drinking water sources. For these reasons they are not included in the discussion of this groundwater province.

Approximately 85 to 90 percent of the Bootheel area has alluvial deposits at the surface. Older formations crop out on and very near the hills and ridges (Miller et al, 1994). Table 24 lists the stratigraphy, approximate thickness, and lithologic characteristics for each of the formations.

GROUNDWATER QUALITY

WATER TYPE

Water type in this province varies with host rock type. Water in the alluvium in the Bootheel and underlying Wilcox Group is calcium-magnesium bicarbonate type. Classification of the water in the Midway Group is difficult since the clay does not contain much water and in fact acts as a retardant to water movement. The McNairy (Ripley) Formation contains water that is calcium bicarbonate to sodium bicarbonate.

TOTAL DISSOLVED SOLIDS

Concentrations of total dissolved solids in water from the Bootheel alluvium range from 60 to 580 mg/l, averaging 250 mg/l (Miller, et al, 1994). The Wilcox Group, which supplies water to most domestic wells in the ridge areas, contains water very similar in chemistry to the alluvial water, however, total dissolved solids tend to be lower than in the alluvium. Average values of TDS are 165 mg/l. McNairy (Ripley) water, though utilized heavi-

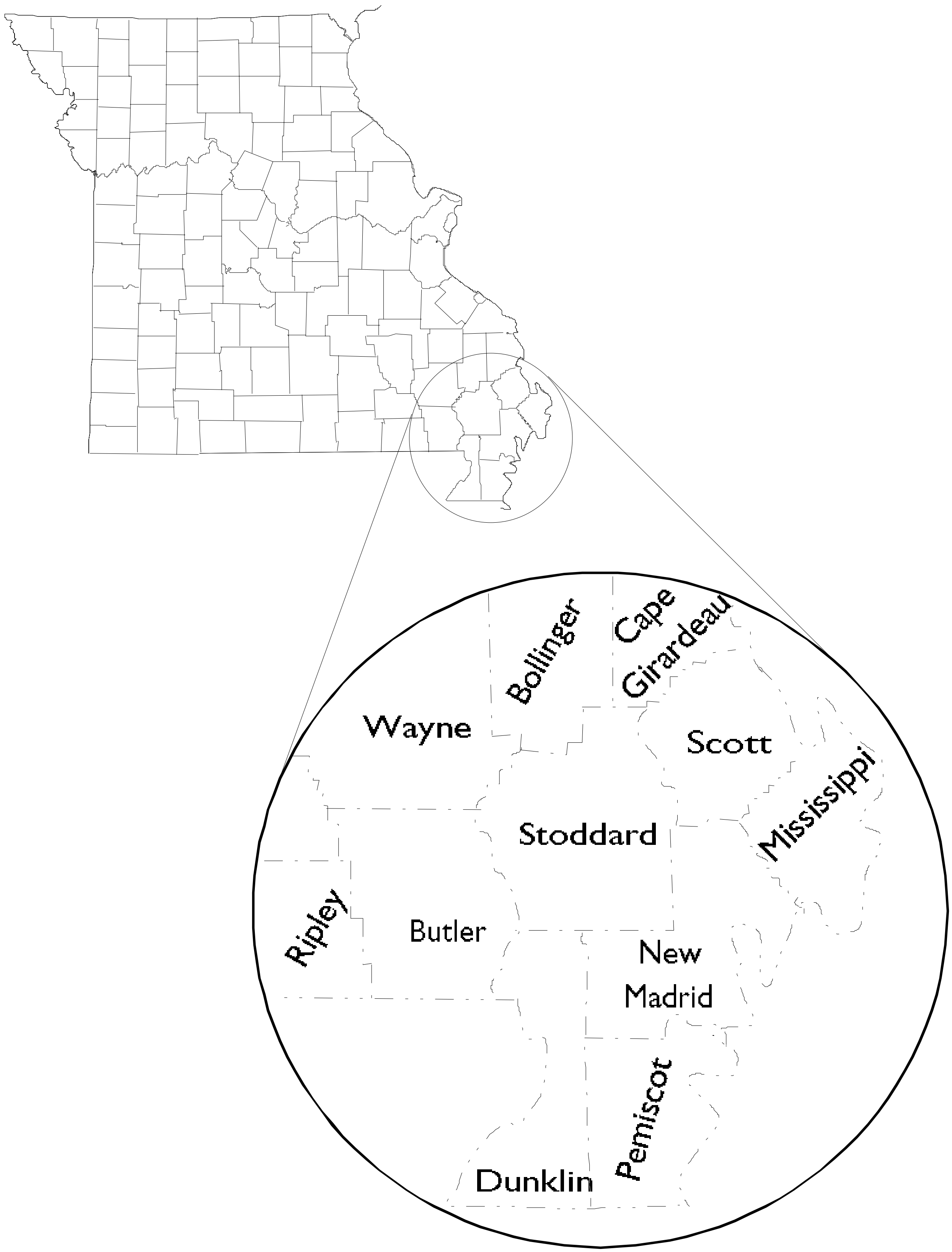


Figure 42. Southeast Missouri groundwater province, including Missouri and Mississippi rivers alluvium.

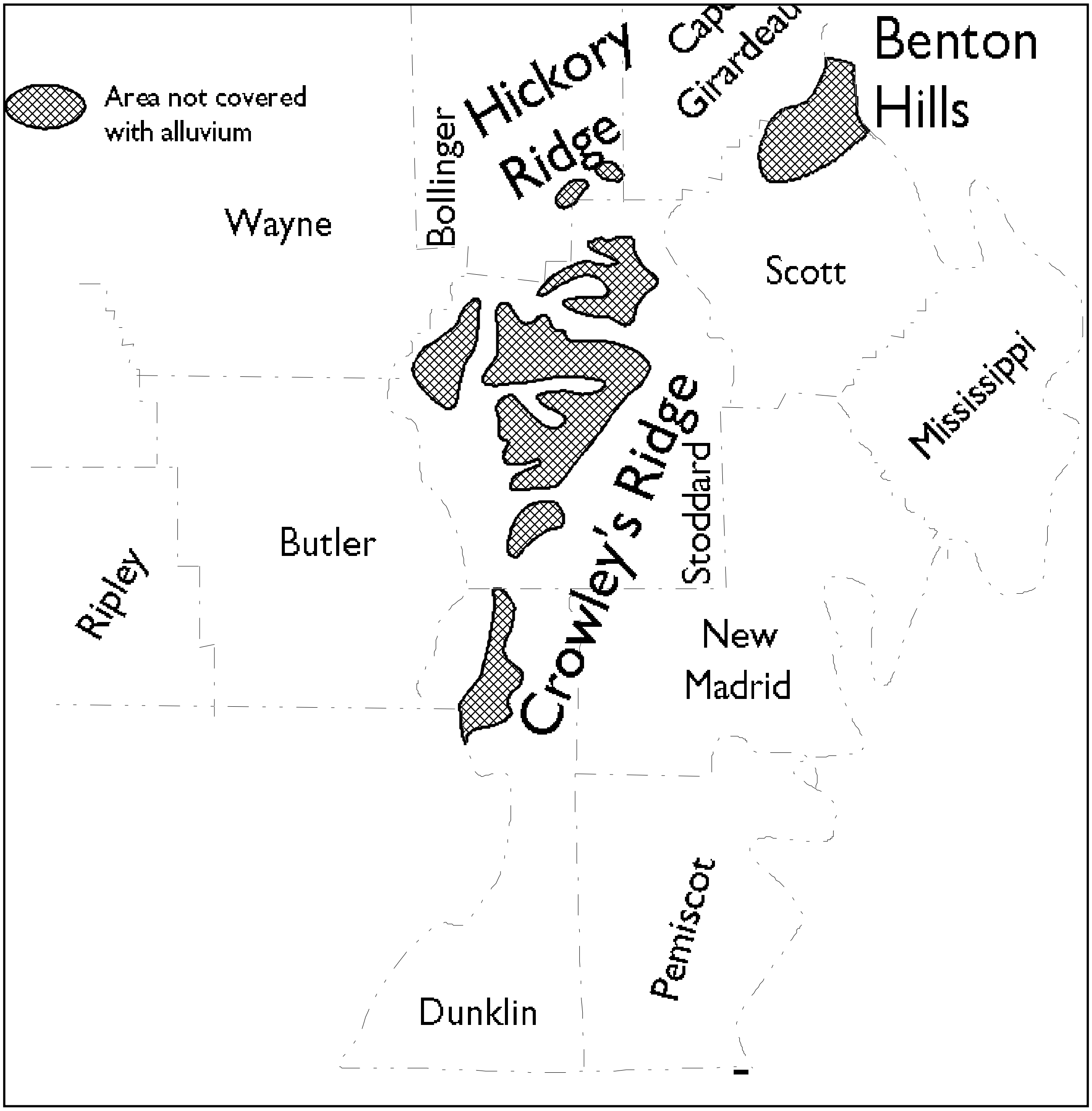


Figure 43. Extent and location of erosional remnants in Southeast Missouri groundwater province (modified from Luckey, 1985)

ly by municipalities, contains more sodium and chloride than the overlying units, and therefore has higher values of TDS. Figure 44 and table 25 show approximate locations of selected wells and chemical analyses. All of these wells obtain water from the alluvial material except for Butler County PWSD #3 and Senath, in Dunklin County.

Sulfate and Chloride

Concentrations of sulfate are typically low in all the water-producing formations. Chloride concentrations, however, can be high enough to pose problems in water from the McNairy (Ripley) Formation, but are generally less than 250 mg/l.

Other Inorganics

Excess iron and manganese, averaging 4.3 mg/l and 0.46 mg/l respectively, pose only minor problems for municipal users of alluvial water, and no problems for the largest users of this water—agricultural irrigators. Wilcox Group water contains fairly high concentrations of iron, averaging 1.89 mg/l, and manganese around 0.2 mg/l. The McNairy (Ripley) Formation has concentrations of iron much lower than the alluvium, averaging only 0.48 mg/l (Luckey, 1985).

Pesticides

The Bootheel area of Missouri is one of the most productive agricultural areas in the state. Water movement in the alluvial material can be quite slow due to low hydraulic gradients. A contaminant captured by the porous material may linger in the strata for quite some time. Though this fact coupled with the application of large quantities of pesticides associated with this land use makes this area quite susceptible to groundwater contamination, there have been very few instances of that to date. Mesko and Carlson sampled 124 wells in the Bootheel for pesticides during 1986 and 1987. The wells were domestic, irrigation, and public water supply wells. Only 4 wells had one or more pesticides detected in concentrations above the MCL (Mesko and Carlson, 1988).

Nutrients

Intensive fertilization of crop land and pasture in this province provides a ready source of nutrient contamination in groundwater. A 1995 study conducted by the Missouri Department of Health showed that approximately 8 percent of small-diameter sandpoint wells, typical to wells in the Bootheel alluvium, contained nitrate above MCL of 10 mg/l.

SYSTEM	SERIES	GEOLOGIC UNIT	THICKNESS	LITHOLOGY (FEET)
Quaternary	Pleistocene	Alluvium	100-200	Gravel, sand, silt, clay
		Loess	35	tan silt with some clay - on uplands
Tertiary	Eocene	Wilcox Group	250-1400	sand, clay, thick basal sands
	Paleocene	Midway Group	200-700	Porter Creek and Clayton mostly clay
Cretaceous	Gulfian	McNairy (Ripley) Formation	0-600	sand, sandy clay
Ls - limestone Dolo - dolomite Silt - siltstone Sh - shale Ss - sandstone				

Table 24 - Stratigraphy of Southeast Missouri groundwater province rocks (after Luckey, 1985).

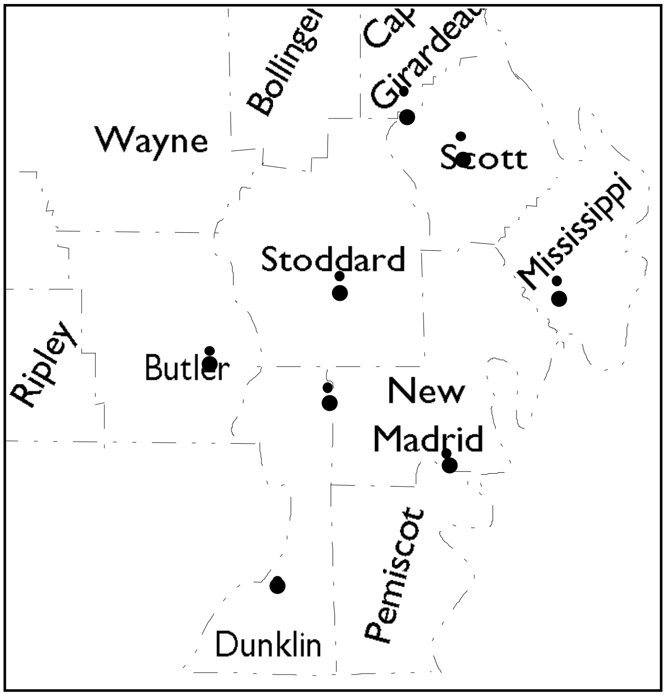


Figure 44. Approximate locations of selected Southeast Missouri municipal water-supply wells.

COUNTY	CITY	pH	ALK	Fe	Mn	Na	K	Ca	Mg	N	SO_4	Cl	F	TDS	TH	Cu
Butler	PWSD #3	7.7	185	<0.1	<0.02	4.1	0.6	42.0	22.1	<0.05	10.0	8.0	<0.1	276	196	0.01
Cape Girardeau	Delta	7.7	280	<0.1	<0.02	9.8	1.4	59.6	30.7	<0.05	11.0	18.0	0.11	335	75	0.03
Dunklin	Malden	7.9	96	0.42	0.36	7.6	1.0	38.0	6.6	<0.05	25.0	8.0	0.10	176	122	<0.01
Dunklin	Senath	8.6	361	<0.1	<0.02	189	2.0	<4.0	<2.0	<0.05	14.0	45.0	0.37	580	<18.0	0.01
Mississippi	East Prairie	8.2	164	<0.1	<0.02	16.2	1.6	49.6	10.9	<0.05	36.0	14.0	0.64	252	169	0.01
New Madrid	Portageville	7.7	215	1.1	0.12	11.4	22.5	66.5	16.8		33.0	17.0		310	235	<0.01
Scott	Oran	6.5	120	0.31	0.1	16.2	4.2	34.5	12.4	0.97	54.0	13.0	<0.2	258	137	0.31
Stoddard	Dexter	7.8	219	<0.1	0.03	45.7	4.9	55.3	16.5	<0.05	<10.0	51.0	0.48	349	206	<0.01

ALK - alkalinity Fe - iron Mn - manganese Na - sodium K - potassium Ca - calcium Mg - magnesium N - nitrogen
SO_4 - sulfate Cl - chloride F - fluoride TDS - total dissolved solids TH - total hardness Cu - copper

Table 25. Chemical analyses for selected Bootheel wells (data source Missouri Department of Natural Resources, 1992).

Springs

The absence of well-defined solutional openings or conduits in the alluvium and other material in this province accounts for the deficiency of springs in the area. The exception to this statement is the occurrence of a very few small springs in the area of the ridges and hills in the Bootheel. These springs issue from the non-alluvial material that is present at the surface. Flow is very small and generally intermittent.

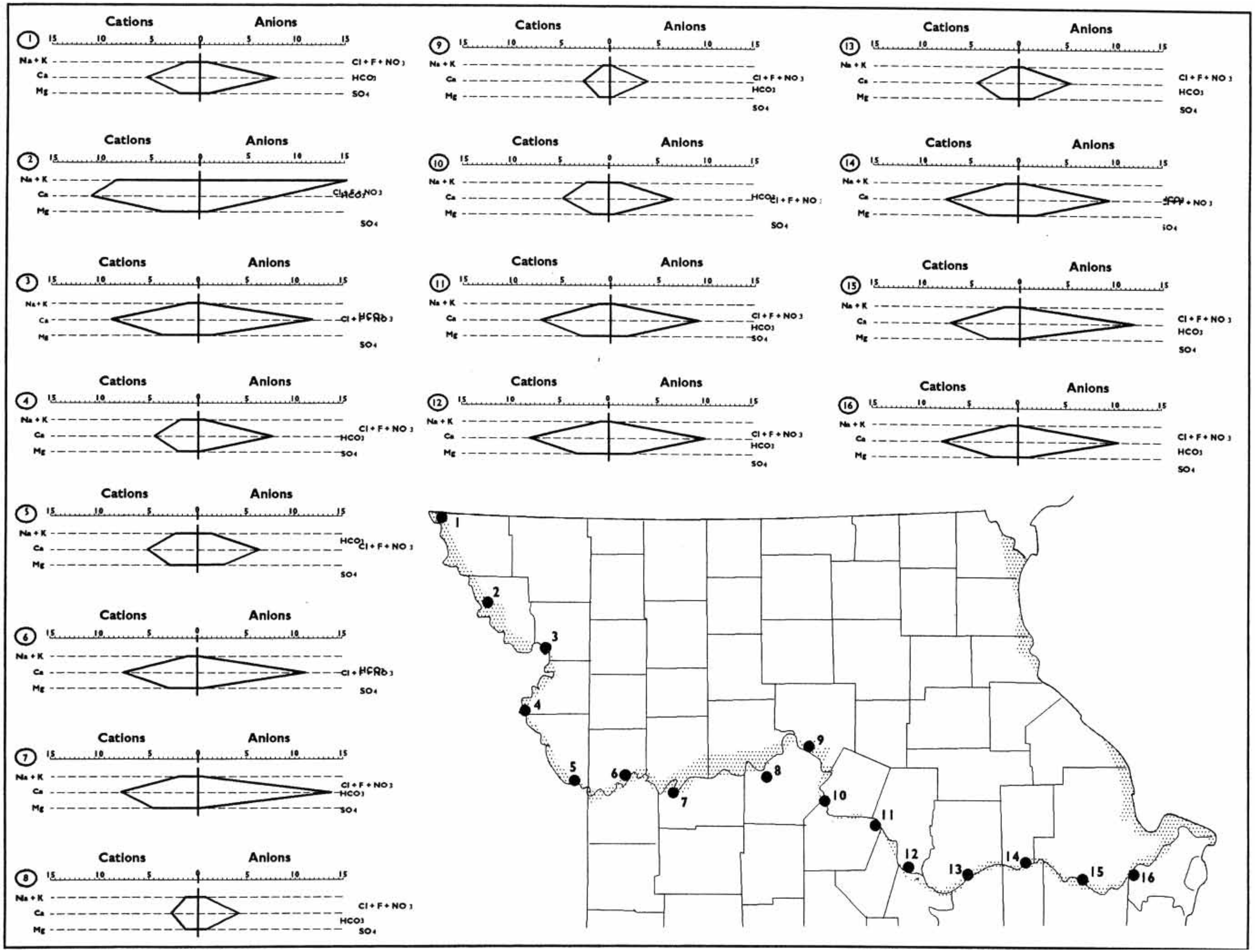


Figure 45. Approximate locations and chemical analyses of selected Missouri River alluvial wells.

MISSOURI RIVER ALLUVIUM

LOCATION AND GEOLOGY

The Missouri River alluvium, with total surface area of approximately 2,000 square miles, provides vast amounts of potable water to Missourians along its entire expanse, and is the largest potential source of fresh water in northwest Missouri. It is composed of unconsolidated gravel, sand, silt, and clay and averages 60 to 100 feet in thickness (Miller et al, 1994). Average saturated thickness ranges from 60 to 80 feet. The alluvium is generally fine-grained at the surface grading downward to coarse-grained at its base. Along its length, the alluvium is underlain by consolidated sandstone, shale, limestone and dolomite. Uplands bordering the alluvium are generally comprised of glacial drift or loess covering sedimentary bedrock. Where the glacial drift is in contact with the alluvium, a hydraulic connection may exist (Emmett and Jeffery, 1969). The units adjacent to and below the alluvium have been discussed in other groundwater province sections and will not be addressed here.

GROUNDWATER QUALITY

WATER TYPE

Some of the water contained in the alluvium originates as direct infiltration of precipitation, some as a result of flooding of streams or sustained high river stages, and a small amount may leak into the alluvium from underlying or adjoining bedrock. These factors impact chemical composition, however, generally water from the Missouri River alluvium is calcium bicarbonate type. Significant amounts of magnesium are present, particularly in the reach upstream from Kansas City, Missouri (Emmett and Jeffery, 1969).

TOTAL DISSOLVED SOLIDS

Missouri River alluvium has highly variable concentrations of total dissolved solids. Variations are related to length of residence time in and chemical composition of the aquifer. High total dissolved solids concentrations, up to 1,200 mg/l, may exist locally. These concentrations generally occur at a distance from the river where the residence time of the water in the aquifer is longer, and interaction with surface water less. Figure 45 shows approximate locations of selected alluvial wells and their corresponding Stiff diagrams used for rapid comparison of water analyses.

SULFATE AND CHLORIDE

Although sulfate and chloride concentrations are generally within recommended limits, locally high concentrations may comprise a significant part of the total dissolved solids. Leakage from highly mineralized bedrock formations is a probable source of these high concentrations.

OTHER INORGANICS

Iron and manganese concentrations vary throughout different reaches of the Missouri River alluvium. Generally, concentrations are too high for domestic use without removal, and secondary maximum contaminant levels of both constituents are often exceeded.

Pesticides

The floodplain of the Missouri River is one of the most productive agricultural areas in the state. Water movement in the alluvial material can be quite slow. A contaminant captured by the porous material may linger in the strata for quite some time. This fact, coupled with the application of large quantities of pesticides associated with this land use, makes these areas quite susceptible to groundwater contamination by pesticides. Ziegler and others sampled wells in Missouri River alluvium in northwest Missouri in 1988 and 1989. Eleven percent of the wells sampled showed pesticide detection, most commonly atrazine, though only one had concentrations above MCL. Wells in the alluvium in extreme northwest Missouri had more occurrences of pesticides than those in the west-central part of the state (Zieglar et al, 1993), and more detections in the shallow wells than in deeper wells.

Nutrients

Intensive fertilization of crop land and pasture in this floodplain provides a ready source of nutrient contamination in groundwater. Nitrates were found in concentrations above the MCL of 10 mg/l in 15 percent of wells sampled during a 1988 study along the northern half of the Missouri River alluvium (Zieglar et al, 1993). All wells but one were less than 45 feet deep. Results are similar for the remainder of the Missouri River alluvium, with slight variations occurring, dependent upon concentration and frequency of fertilizer application. A 1995 study conducted by the Missouri Department of Health showed that approximately 8 percent of sandpoint wells, typical to the Bootheel and river alluvium, contained nitrate above MCL of 10 mg/l.

Springs

The absence of well-defined solutional openings or conduits in the Missouri River alluvium accounts for the deficiency of springs in this province.

MISSISSIPPI RIVER ALLUVIUM

LOCATION AND GEOLOGY

Mississippi River alluvium comprises gravel, sand, silt and clay. Thickness ranges from a few feet to 150 feet, depending upon proximity to the river, and irregularities of the bedrock surface on which it was deposited. Particles are fine-grained near the surface grading to coarse-grained at the base of the material. Water in the alluvium resides in openings between the sand and gravel particles, and where water-saturated, the basal part of the unit is most productive. Though its areal distribution at approximately 800 square miles is less extensive than that of the Missouri River, the floodplain provides an excellent setting for agricultural practices, particularly row cropping.

GROUNDWATER QUALITY

WATER TYPE

Water in the Mississippi River alluvium is recharged by precipitation, flow from underlying and adjacent bedrock, and infiltration of surface water during floods or sustained high river stages. Each of these processes can influence the chemical composition of the water, however, calcium-magnesium bicarbonate type water is prevalent throughout the alluvial aquifer.

TOTAL DISSOLVED SOLIDS

Concentrations of total dissolved solids (TDS) varies widely in the Mississippi River alluvium. Locally high concentrations of sulfate, chloride, and sodium may elevate TDS above the recommended level of 500 mg/l. Generally, TDS range is from 200 to 600 mg/l, with lesser concentrations present in alluvial water nearest the river (Miller et al, 1974).

SULFATE AND CHLORIDE

Concentrations of sulfate and chloride are typically low except where leakage from underlying or adjacent bedrock is occurring. Seven alluvial wells located in St. Charles, St. Louis and Jefferson counties had sulfate concentrations ranging from 13 to 72 mg/l and chloride concentrations from 2.4 to 7.0 mg/l (Miller et al, 1974). Atypical concentrations of sulfate and chloride might be as high as 300 and 350 mg/l, respectively.

OTHER INORGANICS

Excess amounts of iron and manganese are prevalent in Mississippi River alluvium. Values ranging from 2.8 to 14.0 mg/l iron and 0.18 to 2.7 manganese were reported from the wells previously mentioned (Miller, et al, 1974). Fortunately, concentrations in these ranges pose few problems for municipal users and agricultural irrigators that depend upon this groundwater source.

PESTICIDES

Water movement through the Mississippi River alluvium can be quite slow. This, in addition to agricultural land uses with accompanying pesticide application, makes the alluvium particularly susceptible to contamination from pesticides. Mesko and Carlson sampled

groundwater from selected wells completed in the Mississippi River alluvium in southeast Missouri in 1986 and 1987. Their analyses showed detection of various pesticides in 27 percent of the wells sampled although only four detections were above MCL (Mesko and Carlson, 1988).

Nutrients

Due to crop and pasture fertilization, nutrient contamination in groundwater is more common in this province than in other groundwater provinces. Eighteen percent of all wells sampled for nitrate in the Mississippi River alluvium in southeast Missouri had concentrations exceeding 10 mg/l (Mesko and Carlson, 1988). Also, a study conducted by the Missouri Department of Health in 1995 showed that approximately 8 percent of sandpoint wells, which are typical to the Mississippi river alluvium, contained nitrate above MCL of 10 mg/l.

Springs

The absence of well-defined solutional openings or conduits in the Mississippi River alluvium accounts for the deficiency of springs in this province.

GENERAL SURFACE WATER QUALITY

Surface water refers to all water that flows or is impounded upon the earth's surface. It is used for many purposes including drinking water for humans and animals, irrigation, recreation, transportation, and power generation. In Missouri, approximately 60 percent of the population utilizes surface water as their drinking water. Major metropolitan areas located along large rivers account for a large percentage of this use. In addition, northern and western Missouri's poor-quality deep groundwater forces many communities to use surface water supplies.

It is important to characterize surface water quality by comparing conditions to standards designed to prevent harmful constituents from degrading the resource. Missouri Safe Drinking Water Law (RSMo 640.100 - 640.140) designates maximum contaminant levels (MCL) of organic, inorganic, bacteriological, and radiological constituents for public drinking water supplies. Missouri Clean Water Commission Water Quality Standards (10 CSR 20-7) list over 3,200 stream segments and 415 lakes, identify beneficial uses of waters for each, and list criteria designed to protect each of those uses. A companion rule lists effluent regulations which set forth limits for various pollutants that are discharged to waters of the state, and define an antidegradation policy. Water quality standards are revised at least every three years and comply with the latest changes to the Federal Clean Water Act. Both the Drinking Water standards and the Clean Water Law standards will be used in this report for comparison to ambient surface water quality.

Geology and land use can have considerable effects upon the quality of surface water. Soils that contain large amounts of clay or silt can be rather impenetrable and highly erodible, and most precipitation that falls on these soils quickly becomes runoff. Flooding is more frequent, and turbidity, (the measure of the amount of suspended solids in water) is generally higher in streams and rivers that traverse these areas such as the glacial drift of northern Missouri and the Osage plains of western Missouri. Conversely, the thin soils and highly weathered bedrock in the Salem and Springfield plateaus absorb most of the precipitation, thus groundwater provides adequate water for streams to maintain flow year round.

Materials that come in contact with surface water contribute dissolved constituents to its composition. Calcium, magnesium, sulfate, chloride, bicarbonate, silica, iron, sodium, and potassium may all be found in varying concentrations in surface water. Various strains of bacteria are present in virtually all surface water, and if it is used as a drinking water supply, disinfection is required. Nutrients, such as nitrogen and phosphorus, are also found in most surface waters. Table 26 lists common constituents found in surface water, their sources and environmental significance.

The physiography of a region greatly influences its land use. For example, the plains and alluvial valleys of the state are ideal

CONSTITUENT	COMMON SOURCES	ENVIRONMENTAL SIGNIFICANCE
Dissolved Oxygen	Introduced from the atmosphere also a product of aquatic plants	Necessary for aquatic life; deficiency can result from assimilation of organic wastes or rapid growth and decay of algae
Fecal coliform bacteria	Sources include effluent from sewage-treatment plants and runoff from pastures, feedlots, and urban areas	Presence indicates contamination of water by wastes from humans and other warm-blooded animals
Sulfate	Occurs in some rocks; also in mine runoff, industrial wastewater discharge, and atmospheric deposition	Concentrations exceeding a natural, background level indicate contamination from human activity; in sufficient quantity, can cause water to be unsuitable for public supply, can harm aquatic life
Dissolved solids	A result of rock weathering; also in agricultural runoff and industrial discharge	In sufficient quantity, can cause water to be unsuitable for public supply, agriculture, and industry; can harm aquatic organisms
Nitrate plus nitrate as nitrogen	Nonpoint sources are agricultural and urban runoff; a major point source is wastewater discharge	Plant nutrient that in sufficient quantity, can cause algal blooms and excessive growth of higher aquatic plants in bodies of water; can cause water to be unsuitable for public supply
Phosphorus	Occurs in some rocks and sediments, agricultural and urban runoff, and industrial and municipal wastewater discharge	Plant nutrient that, in sufficient quantity, can cause algal blooms and excessive growth of higher aquatic plants in bodies of water
Suspended sediment	A result of rock erosion; also induced by disturbances of land cover due to fires, floods, and human activities such as mining, logging, construction, and agriculture	Can be detrimental to aquatic organisms, can fill reservoirs and impair recreational use of water
Pesticides supply	Runoff from agricultural areas	Can cause water to be unsuitable for public water

Table 26. Sources and environmental significance of selected surface water-quality constituents (Modified from Davis and Howland, 1991)

for extensive row cropping while the St. Francois Mountains are best utilized as forests and pasture. Most land uses have accompanying potential contaminants specific to the use. For instance, pesticides and fertilizers are prevalent in agricultural regions, mine wastes accompany mined areas, and industrial wastes and sewage are typically in proximity to population centers. Each of these pollutants has the potential to affect surface water, either from what is termed a point source such as a wastewater treatment plant discharge, or from a nonpoint source like runoff from an agricultural field.

By far, the greatest influence on surface water quality is the volume of flow in the stream and the relationship to a hydrographic event at the time of sampling (Ford, written comm., 1996). However, large sources of pollutants may also impact the water quality of streams particularly if the pollutant discharges to a relatively small stream. Large pollutant discharges to large streams involve dilution of the pollutant and the effects on water quality of that stream may not be as adverse.

In the following basin discussions, quarterly concentrations of various constituents are listed for one or more years. These values are provided only as examples, and in the instances where water quality data from more than one year is listed, no trends should be inferred between the data. More than 10, and preferably 15 years or more of continuous data are necessary to reasonably infer trends in surface water quality. However, it is possible to compare specific constituents between streams in different areas of the state, or to study changes in water chemistry as the stream traverses different physiographic regions. Suspended solids, nitrogen and phosphorus concentrations will be stressed because these three constituents are focal points for control of nonpoint source pollution problems. High total dissolved solids, sulfate, chloride, fecal coliform and fecal streptococcus are concerns when discussing drinking water and thus are a focus in this report.

All of Missouri is drained either directly or indirectly by the Mississippi River and its tributaries. Major river systems contributing drainage to the Mississippi River are the Missouri River, Arkansas River, and the White River. For ease of discussion, these basins will be divided further to include 1) upper Mississippi River and its tributaries, 2) Missouri River tributaries north of the Missouri River, 3) Missouri River tributaries south of the Missouri River, 4) lower Mississippi River and its tributaries, 5) White River tributaries, and 6) Arkansas River tributaries (figure 46).

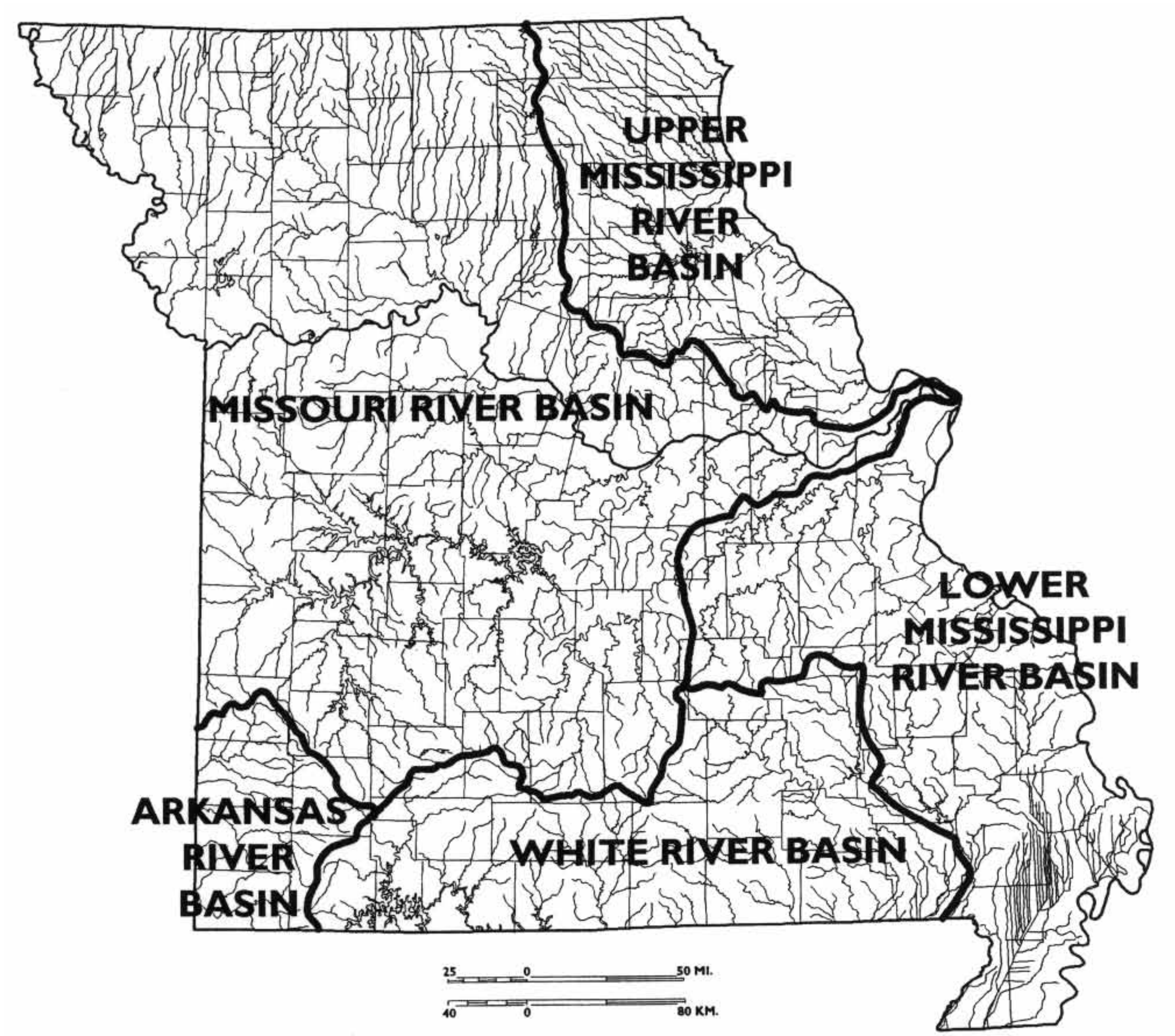


Figure 46. Major river basins in Missouri.

PESTICIDES

The subject of pesticide contamination of surface waters can best be discussed using a statewide approach. Pesticide applications are concentrated in the spring and summer months accounting for highly variable concentrations found in samples from rivers and lakes. Rivers and streams show the seasonality of pesticide use best because runoff from fields can reach sampling points on rivers within a few hours to a few days. Conversely, runoff entering small and medium-sized reservoirs may move slowly downlake for a few weeks to a few months before it reaches lake sampling points, which are typically near dams (Ford, 1994). Annual variations in pesticide levels in surface water can be the result of the amount of total precipitation for the year. Additionally, during dry years, pesticides in lakes are not naturally diluted and flushed out of the lakes, therefore pesticide levels in the lakes may not reflect the true amount leaving the fields. Crop rotation may change the type of pesticide, particularly in small watersheds.

One objective of the U.S. Geological Survey's National Water-Quality Assessment Program Ozark Plateaus Study Unit was to analyze pesticide data for the years 1970 to 1990. Portions of northern Arkansas, eastern Kansas, and northeastern Oklahoma are included in the study unit, which is primarily comprised of the Ozark plateaus physiographic region in southern Missouri. Of the 1,002 samples from 140 surface-water sampling sites within the study unit, only 18 sites within Missouri had pesticide concentrations above detection levels. Five of those sites were in the Osage Plains region, 8 were in the Springfield Plateau area, and 5 were in the Salem Plateau (Bell et al, 1996). The most detections were from sampling sites within the agricultural areas. These samples were of raw, filtered water, and it is important to note that none of the detections were above Missouri Safe Drinking Water Law maximum contaminant levels (MCL).

Likewise, recent studies indicate that water supplies in the agricultural plains areas of northern and western Missouri and the Bootheel area where most pesticide applications occur, show the most pesticide detections. A summary of pesticides monitoring of Missouri public drinking water supplies in 1995 indicates that 66 of 100 supplies using a river, lake or impoundment had pesticide concentrations above detection levels (figure 47). However, only 10 of these supplies had atrazine, the most frequently detected pesticide in concentrations above MCL. By the end of 1995 all 10 water supply systems were back in compliance with safe drinking water standards (DNR, 1996).

In general, runoff from agricultural areas where pesticides have been applied will at some time contain one or more pesticides at concentrations above detection level. Factors such as amount and frequency of precipitation and amount, solubility and transport characteristics of pesticide applied determine the level of contamination to the receiving water body.

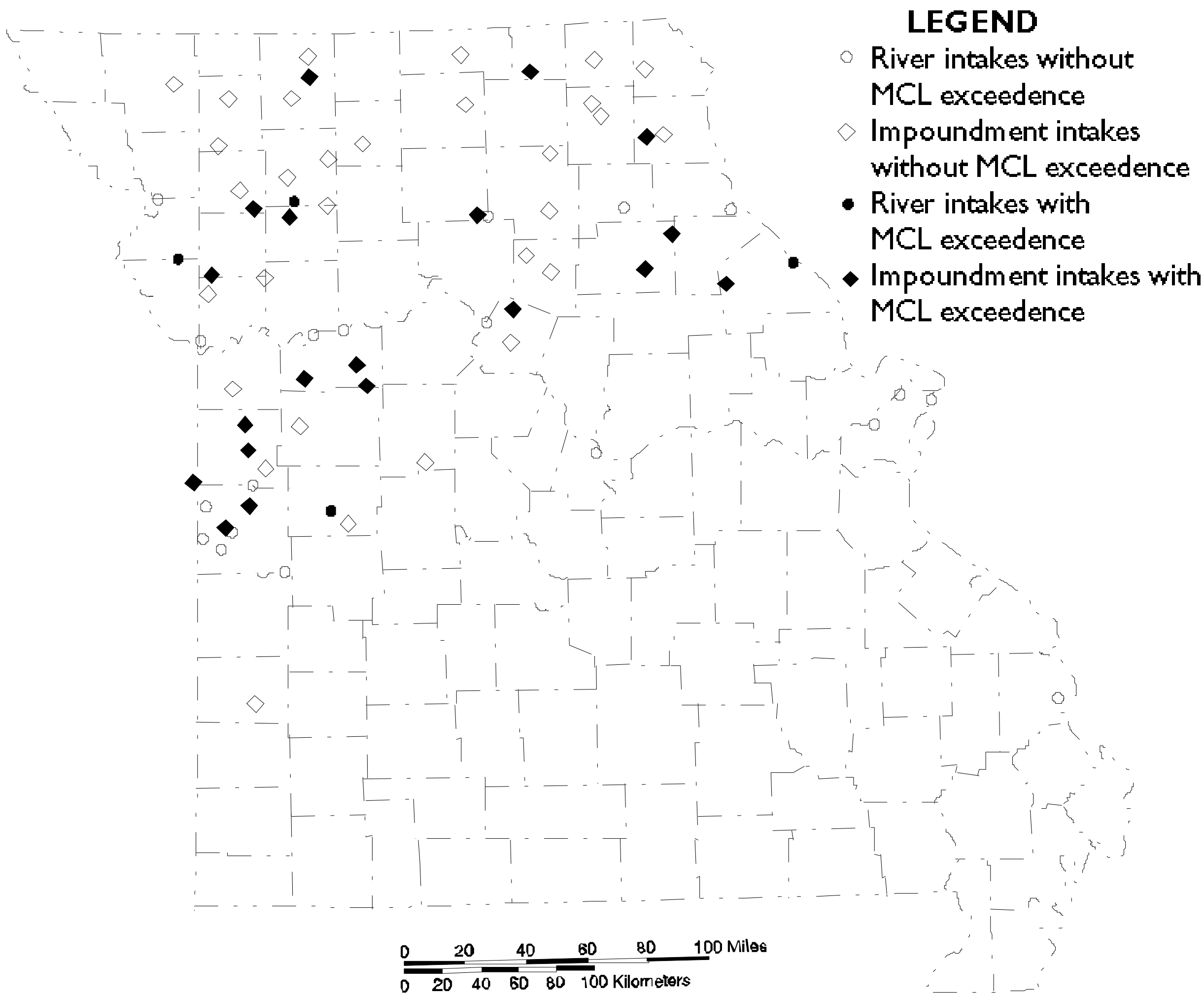


Figure 47. Approximate locations of public water supplies having pesticide detection during June 1994 to March 1996.

UPPER MISSISSIPPI RIVER TRIBUTARIES

BASIN DESCRIPTION AND HYDROGEOLOGY

Excluding a northeastern segment of border provided by the Des Moines River, the Mississippi River forms the entire eastern boundary of Missouri, except where changes in the channel have caused portions of Illinois, Kentucky, and Tennessee to lie west of the channel. Its length along the border measures 485 miles (*Missouri Water Atlas*, 1986), and the river is divided into the upper Mississippi and lower Mississippi rivers. Others define the **upper Mississippi River** as the length above its confluence with the Ohio River. In this report the **upper Mississippi River** is defined as that reach of the river that is upstream from the confluence of the Missouri and Mississippi rivers. Drainage area for this portion of the river is approximately 7,790 square miles (Vandike, 1995). Major Missouri tributaries in the basin are the **Des Moines**, **Fox**, **Wyaconda, Fabius, North, Salt, and Cuivre** Rivers (figure 48)**.** These watersheds combine to drain approximately 6,700 square miles within Missouri (Vandike, 1995). The remaining 1,090 square miles of the total drainage is provided by **South River, Bear Creek, Noix Creek, Buffalo Creek, Ramsey Creek, Guinns Creek, Bryants Creek, Bobs Creek, Peruque Creek,** and **Dardenne Creek**, and smaller streams that drain directly into the Mississippi River.

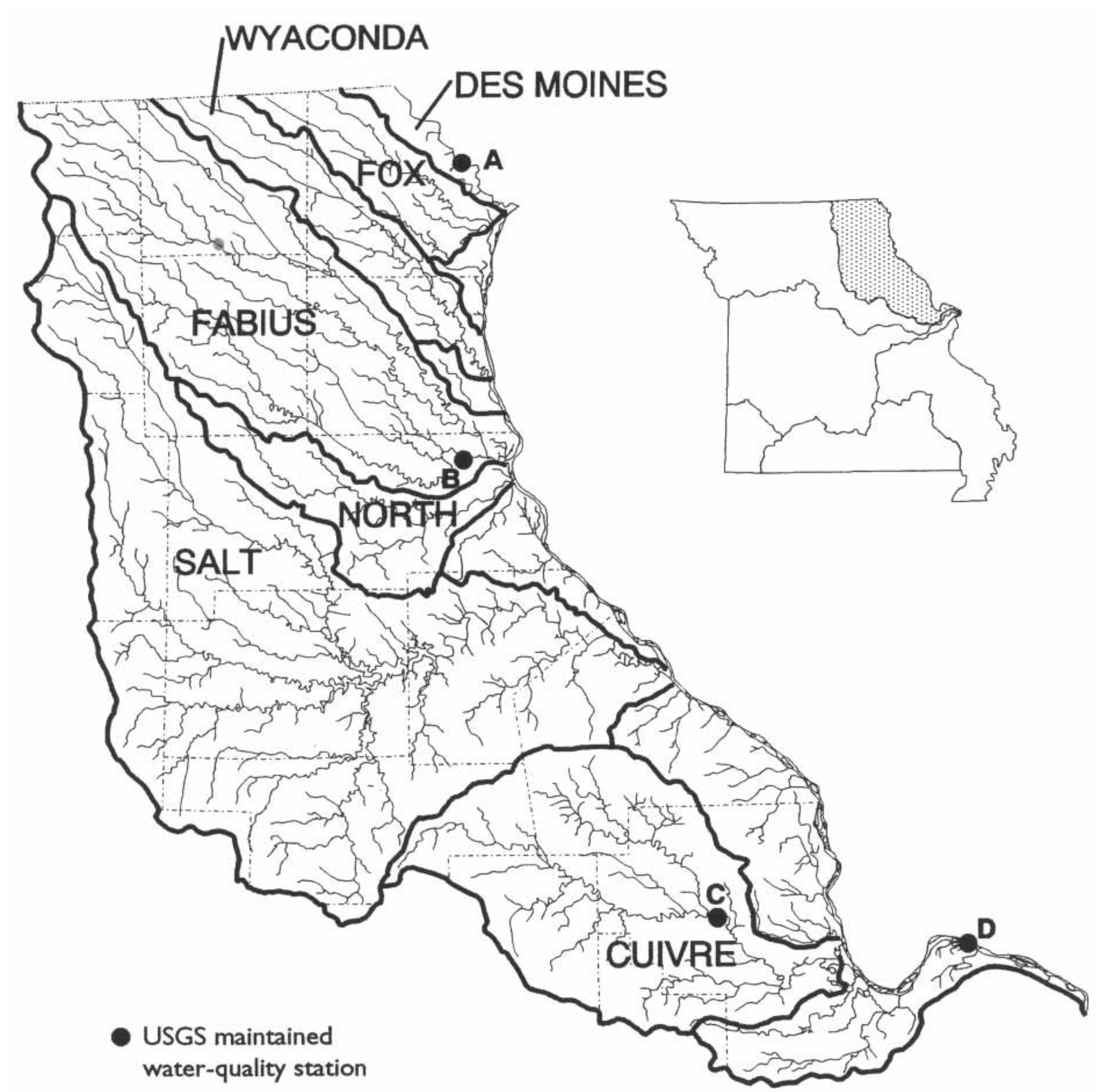
Sedimentary rocks of Pennsylvanian age, primarily shales and sandstones, and Mississippian limestones comprise most of the bedrock geology in the upper Mississippi River basin. These formations may be overlain by glacial drift with thicknesses up to several hundred feet. Loess (windblown silt) covers the drift in some areas. Soils with high clay content retard downward migration of water, and result in minimal groundwater recharge, causing very low stream base flows during dry periods. The area has extensive plains and gently rolling hills that are conducive to livestock production and extensive agricultural crops, particularly corn, soybeans, hay, wheat, and sorghum.

Figure 48 shows that drainage patterns in the northern part of the basin generally trend southeast, and the basins have greater length than width (Vandike, 1995).

SURFACE WATER QUALITY

Main Stem Mississippi River

Surface water type reflects the composition of the underlying rock formations and soils over which it flows. Typical water type for the entire **upper Mississippi River** basin is calcium-magnesium bicarbonate. Quarterly water quality records from the **Mississippi River** near Grafton, IL (directly east of St. Charles County, Missouri) in 1993 show that calcium-magnesium ratios average 2:1. Total dissolved solids (TDS) concentrations range from 238 mg/l to 315 mg/l, while sulfate, chloride, and metals concentrations are all very low, well within Missouri Safe Drinking Water maximum contaminant levels (MCL) (Table 27). Nitrate plus nitrite as nitrogen ranged from 2.7 mg/l to 3.8 mg/l; fertilizer and food processing industries in southern Iowa



STATION ID NO.	STATION NAME	COUNTY	DRAINAGE AREA (SQ MI)
A	Des Moines River at St. Francisville	Clark	14,300
B	S. Fabius River near Taylor	Marion	620
C	Cuivre River near Troy	Lincoln	903
D	Mississippi River below Grafton, IL	Jersey, IL	171,300

Figure 48. Upper Mississippi River tributaries in Missouri.

and northern Missouri may be major sources of the high nitrate levels (DNR, 1995.) Atrazine, alachlor, and cyanazine were measured above their detection limits, but none of the concentrations were above the MCL. Although there is currently no MCL for phosphorus, it is a nutrient that leads to excessive algal growth. Phosphorus is associated with both agricultural land uses, where it is associated with and attached to sediment, and urban treated waste-

CONSTITUENT	FALL	WINTER	SPRING	SUMMER
Instantaneous discharge, (ft^3/second)	120,000	157,000	273,000	429,000
Temperature, (°Celsius)	6.5	0.5	8.0	24.0
Specific Conductance, (µs/cm)	394	518	325	75
pH, whole water, field measurement	8.1	8.0	7.5	7.5
Oxygen, dissolved (mg/l)	10.8	13.0	11.6	6.0
Fecal coliform, (colonies/100 ml)	80	130	130	1,250
Fecal streptococci, (colonies/100 ml)	130	220	160	510
Alkalinity, (mg/l as $CaCO_3$)	186	179	132	142
Nitrate + Nitrite, total as N (mg/l)	2.8	3.3	2.7	3.8
Phosphorus, dissolved (mg/l)	0.44	0.14	0.33	0.25
Calcium, dissolved (mg/l)	53	55	42	64
Magnesium, dissolved (mg/l)	22	22	15	51
Sodium, dissolved (mg/l)	19	16	12	7
Potassium, dissolved (mg/l)	3.6	3.1	5.6	3.5
Sulfate, dissolved (mg/l)	51	45	30	62
Chloride, dissolved (mg/l)	29	30	24	12
Fluoride, dissolved (mg/l)	0.3	0.1	0.2	0.2
Total solids, dissolved (mg/l)	315	294	238	243
Barium, dissolved (µg/l)	49	61	57	47
Aluminum, dissolved (µg/l)	20	30	<10	10
Iron, dissolved (µg/l)	13	34	12	6
Manganese, dissolved (µg/l)	16	11	2	<1
Nickel, dissolved (µg/l)	2	3	<1	2
Strontium, dissolved (µg/l)	150	100	130	20
Atrazine, dissolved (µg/l)	0.4	—	0.33	2.2
Alachlor, dissolved (µg/l)	0.04	—	<0.05	0.29
Cyanazine, dissolved (µg/l)	0.13	—	0.2	1.2

Table 27. Quarterly water quality data from Mississippi River near Grafton, Illinois, 1993. (Data source USGS, 1994)

water discharges. Values of dissolved phosphorus at the Grafton sampling site ranged from 0.14 mg/l to 0.44 mg/l. Near its confluence with the Missouri River in St. Charles County, Missouri, the **Mississippi River** receives drainage from several small tributaries. Within the watershed of **Peruque Creek, Lake St. Louis,** a 525-acre lake is listed by the Missouri Department of Natural Resources as having one or more of its beneficial uses impaired by the presence of chlordane. Urban runoff from improper insecticide treatment is the probable source of the chlordane. All uses of chlordane were canceled by the U.S. Environmental Protection Agency in 1988, and although it is no longer available commercially in the United States it is persistent as a contaminant. **Peruque, Dardenne,** and **Spencer** Creeks also are listed as having a total of 13.5 miles of aquatic habitat loss due to effects of channelization (DNR, 1996).

Des Moines, Fox, and Wyaconda Rivers

A small percentage of the **Des Moines River** basin**,** and approximately half of the **Fox** and **Wyaconda** Rivers basins lie in Missouri. Drainage from fertilizer and food processing industries in southern Iowa and from agricultural land in Iowa and northern Missouri may be sources of the high nitrate plus nitrite as nitrogen found in samples collected from the **Des Moines River** near St. Francisville, Missouri, in 1991. Table 28 shows that quarterly nitrate plus nitrite as nitrogen concentrations were quite high, ranging from 3.6 mg/l to 11.0 mg/l (MCL is 10 mg/l nitrate plus nitrite as nitrogen). All other constituents sampled were within normal ranges and below MCLs. High soil erosion rates and channelization on the **Wyaconda** and **Fox** Rivers have caused degradation of the aquatic habitat of these rivers by increasing siltation and maximum water temperatures (DNR, 1995). Point sources such as wastewater effluent discharges have little significance in these basins.

Fabius and North Rivers

South, Middle, and **North Fabius** rivers converge to become the **Fabius River** just a few miles upstream from its confluence with the Mississippi River. These three branches flow in a southeasterly direction over basins that are predominantly covered with glacial drift.

Much of the **North Fabius River** basin has aquatic habitat that has been degraded by sedimentation caused by extensive channelization. LaBelle Lake, a 112-acre lake in the **Middle Fabius River** basin is listed by the Missouri Department of Natural Resources as being adversely affected by atrazine (DNR, 1996). Table 29 includes water-quality data from 1984 and 1995 from a U.S. Geological Survey water-quality station on the **South Fabius River** near Taylor, Missouri.

The **North River** basin also is underlain by low-permeability glacial drift and beneath that Mississippian sedimentary rocks. Not enough groundwater is released to maintain flow to surface streams during dry weather. Row-cropping is the predominant land use in this basin, thus soil erosion and runoff containing agricultural chemicals are the major sources of contaminants to surface water. One Monroe City lake in this watershed on the Monroe-Ralls County line has 17 acres adversely impacted by siltation and atrazine (DNR, 1996).

Salt River

The **Salt River** basin contains four major branches; the **North Fork Salt, Middle Fork Salt, Elk Fork,** and **South Fork Salt**. These branches converge to form **Mark Twain Lake**, which is impounded by Clarence Cannon Dam. Flow in the **Salt River** below Mark Twain Lake is primarily controlled by releases from the dam. Approximately 10 miles of the **Salt River** below the dam are affected by low dissolved oxygen concentrations (DNR, 1996). Generally, point source discharges are not significant to the overall water quality in this basin, with the exception of impacts resulting from sewage treatment plant discharges by the cities of New London and Bowling Green (DNR, 1995).

North Fork Salt River basin is underlain by loess and glacial drift and in some valleys, Pennsylvanian or Mississippian rocks.

CONSTITUENT	FALL	WINTER	SPRING	SUMMER
Instantaneous discharge, (ft^3/second)	1,960	8,340	24,800	2,230
Temperature, (°Celsius)	3.5	5.0	18.0	26.0
Specific Conductance, (µs/cm)	624	501	532	549
pH, whole water, field measurement	8.5	8.0	8.0	8.2
Oxygen, dissolved (mg/l)	13.1	12.9	10.4	7.6
Fecal coliform, (colonies/100 ml)	46	1,400	58	130
Fecal streptococci, (colonies/100 ml)	34	240	90	100
Alkalinity, (mg/l as $CaCO_3$)	218	216	164	43
Nitrate + Nitrite, total as N (mg/l)	3.6	4.5	11.0	9.2
Phosphorus, dissolved (mg/l)	0.05	0.30	0.13	0.11
Calcium, dissolved (mg/l)	70	92	72	73
Magnesium, dissolved (mg/l)	27	32	20	22
Sodium, dissolved (mg/l)	23	34	7.5	8.1
Potassium, dissolved (mg/l)	3.9	4.6	2.8	3.2
Sulfate, dissolved (mg/l)	69	98	41	41
Chloride, dissolved (mg/l)	34	51	23	81
Fluoride, dissolved (mg/l)	0.20	0.40	0.40	0.40
Total solids, dissolved (mg/l)	372	310	328	360
Barium, dissolved (µg/l)	92	100	88	97
Aluminum, dissolved (µg/l)	<10	<10	<10	10
Iron, dissolved (µg/l)	12	22	51	5
Manganese, dissolved (µg/l)	16	34	6	7
Nickel, dissolved (µg/l)	1	4	2	2
Strontium, dissolved (µg/l)	290	330	180	190

Table 28. Quarterly water quality data from Des Moines River near St. Francoisville, Missouri, 1991. (Data source USGS, 1992)

CONSTITUENT	FALL 1984	FALL 1995	WINTER 1984	WINTER 1995	SPRING 1984	SPRING 1995	SUMMER 1984	SUMMER 1995
Instantaneous discharge, (ft³/second)	3	4	100	35	1,170	219	38	121
Temperature, (°Celsius)	13.5	12.5	0.5	3.5	12.0	13.8	27.0	28.5
Specific Conductance, (µs/cm)	428	421	410	405	238	412	443	278
pH, whole water, field measurement	8.2	8.1	7.3	7.2	7.6	8.1	8.4	8.1
Oxygen, dissolved (mg/l)	9.2	9.8	11.4	12.7	8.8	9.7	6.2	9.5
Fecal coliform, (colonies/100 ml)	210	67	830	70	1,300	66	420	168
Fecal streptococci, (colonies/100 ml)	—	4,400	—	193	—	2,012	—	56
Alkalinity, (mg/l as $CaCO_3$)	169	150	97	110	68	106	164	106
Bicarbonate, dissolved (mg/l)	—	184	—	135	—	130	—	131
Nitrate + Nitrite, total as N (mg/l)	0.07	0.15	6.6	0.7	1.4	0.34	<0.1	<0.02
Phosphorus, dissolved (mg/l)	0.05	0.09	0.10	0.12	0.17	0.14	0.08	0.06
Calcium, dissolved (mg/l)	58	56	—	59	27	—	56	—
Magnesium, dissolved (mg/l)	15	12	9	14	6.5	—	12	—
Sodium, dissolved (mg/l)	15	12	13	15	6.4	—	12	6.6
Potassium, dissolved (mg/l)	3.5	5.1	3.7	5.1	3.2	—	4.1	3.8
Sulfate, dissolved (mg/l)	47	46	74	77	33	—	50	22
Chloride, dissolved (mg/l)	12	11	12	22	4.0	—	9.1	8.8
Fluoride, dissolved (mg/l)	0.2	0.2	0.2	0.2	0.1	—	0.2	0.2
Total solids, dissolved (mg/l)	260	254	276	—	150	—	245	172
Total solids, suspended (mg/l)	6	68	21	8	270	—	20	60
Aluminum, dissolved (µg/l)	—	<20	—	<20	—	—	—	100
Iron, dissolved (µg/l)	60	15	150	9	820	—	12	120
Manganese, dissolved (µg/l)	24	140	190	290	<20	—	14	1
Zinc, dissolved (µg/l)	<10	<4	<10	7	<10	—	21	4
Simazine, dissolved (µg/l)	—	0.02	—	—	—	<0.008	—	0.02
Atrazine, dissolved (µg/l)	—	0.27	—	—	—	0.67	—	1.68
Alachlor, dissolved (µg/l)	—	<0.009	—	—	—	0.02	—	0.04
Cyanazine, dissolved (µg/l)	—	0.05	—	—	—	0.03	—	0.85

Table 29. Quarterly water quality data from South Fabius River near Taylor, Missouri, 1984 and 1995. (Data source USGS, 1985 and 1996.)

It is predominantly agricultural and has the similar contaminants as described previously for other tributaries to the upper Mississippi River. Extensive channelization in much of the basin has reduced the diversity and quality of aquatic habitat. Concentrated levels of ammonia, low levels of dissolved oxygen, and abnormal algal growth may result from livestock wastes in streams, particularly during periods of low flow (DNR, 1995). Schuyler County Public Water Supply District #1 includes a 29-acre lake that is located in the upper end of the basin. This lake is included on the Missouri Department of Natural Resources impaired waters list for atrazine (DNR, 1996). Two Monroe City lakes have a total of 149 acres adversely impacted by atrazine and siltation. No other significant point source impacts are present in the basin.

Middle Fork Salt River and **South Fork Salt River** basins have geology similar to that of the **North Fork Salt River**, however, the terrain is generally more flat to rolling hills with little topographic relief. Land use is primarily agricultural with associated problems such as runoff containing agricultural chemicals. Sedimentation from channelization is also a concern with respect to degradation of aquatic habitat. Additionally, oxidation of pyrites in coal mining spoils in northern Audrain, southern Ralls and southern Monroe counties has increased sulfate levels in surface water. However, these levels are well below Missouri Safe Drinking Water recommended secondary MCL for public drinking water supplies (DNR, 1995).

Mark Twain Lake, located in the **Salt River** basin is used for water supply, recreation and flood control. At normal pool elevation the length of the total impounded stream miles of its major arms is 99 miles. Surface area at this elevation is 18,600 acres, and shoreline length is 285 miles. Water quality problems in **Mark Twain Lake** are due to activities within the watersheds. With 86 percent of its watershed in agriculture, potential nonpoint sources previously mentioned for agricultural areas apply here as well. High concentrations of total suspended solids (TSS), nutrients and agricultural chemicals adversely impact this watershed. Additionally, in 1988, a health advisory was issued against consumption of fish from the uppermost 200 acres of the North Fork Arm due to chlordane contamination (DNR, 1995.) This advisory has been modified to limit the consumption of bottom-feeding fish to one pound per week per person (Carlson, pers comm, 1997). The U.S. Environmental Protection Agency canceled chlordane, commonly used for termite control around foundations in 1988, and it is no longer commercially available. Typical concentrations of TSS in the upper arms of the lake are <20 mg/l during dry periods and >200 mg/l after flooding. Main lake areas TSS concentrations generally range from <10 mg/l to >50 mg/l (Knowlton and Jones, 1992). Variations in total phosphorus concentrations mimic the TSS values for different flow conditions ranging from 100 ug/l to 250 ug/l for upper arms of the lake and 65 to 87 ug/l in main lake areas. Total nitrogen averages 1.5 to 2.2 mg/l and 1.1 to 1.3 mg/l in the upper and main lakes respectively (Knowlton and Jones, 1992).

CUIVRE RIVER

The **Cuivre River** basin is the southernmost of the **upper Mississippi River** tributaries. The river flows east to the Mississippi River over Pennsylvanian and Mississippian-age rocks and glacial drift and loess. Land use in the upper part of the basin is predominantly agricultural while the lower portion is mainly forest and pasture. Table 30 lists quarterly data for 1984 and 1995 from a U. S. Geological Survey water-quality station on the **Cuivre River** near Troy, Missouri. TDS concentrations are slightly lower than those from streams previously discussed in predominantly agricultural areas.

The upper part of the basin contains two areas of concern with respect to point source contamination. Treated sewage effluent from Montgomery City has impacted approximately one mile of **Elkhorn Creek**, and a short segment of **Indian Camp Creek** in St. Charles County is impaired by leachate from a landfill (DNR, 1995).

CONSTITUENT	FALL 1984	FALL 1995	WINTER 1984	WINTER 1995	SPRING 1984	SPRING 1995	SUMMER 1984	SUMMER 1995
Instantaneous discharge, (ft³/second)	38	128	402	194	894	1,790	43	800
Temperature, (°Celsius)	14.0	10.5	0.5	0.5	12.0	17.0	25.0	25.5
Specific Conductance, (µs/cm)	408	421	286	435	272	250	325	291
pH, whole water, field measurement	7.7	7.6	7.2	7.5	7.6	7.5	7.5	7.3
Oxygen, dissolved (mg/l)	6.3	11.2	9.2	15.0	8.0	8.9	5.0	5.0
Fecal coliform, (colonies/100 ml)	740	—	720	—	140	1,900	1,000	1,600
Fecal streptococci, (colonies/100 ml)	—	104	—	26	—	1,520	—	29,800
Alkalinity, (mg/l as $CaCO_3$)	187	168	78	145	94	113	123	115
Bicarbonate, dissolved (mg/l)	—	205	—	177	—	107	—	62
Nitrate + Nitrite, total as N (mg/l)	0.21	0.12	4.0	1.1	1.9	1.8	1.4	2.3
Phosphorus, dissolved (mg/l)	0.08	0.02	0.13	0.02	0.12	0.12	0.09	0.19
Calcium, dissolved (mg/l)	64	62	—	59	37	34	49	21
Magnesium, dissolved (mg/l)	12	9.9	5.4	8.9	6.6	5.1	7.8	3.1
Sodium, dissolved (mg/l)	8.8	9.2	7.4	11.0	5.8	5.2	7.8	4.7
Potassium, dissolved (mg/l)	3.5	3.7	3.7	4.0	3.0	4.8	4.5	8.0
Sulfate, dissolved (mg/l)	23	17	33	31	26	13	23	10
Chloride, dissolved (mg/l)	16	23	10	16	5	8	9.7	8.1
Fluoride, dissolved (mg/l)	0.20	0.10	0.20	0.10	0.10	0.20	0.20	0.20
Total solids, dissolved (mg/l)	250	244	207	242	182	166	191	124
Barium, dissolved (µg/l)	—	120	—	81	—	70	—	61
Aluminum, dissolved (µg/l)	—	<10	—	<10	—	80	—	190
Iron, dissolved (µg/l)	20	11	170	11	190	77	20	200
Manganese, dissolved (µg/l)	700	410	120	230	86	22	270	8
Nickel, dissolved (µg/l)	—	2	—	2	—	2	—	2
Strontium, dissolved (µg/l)	—	120	—	110	—	77	—	48

Table 30. Quarterly water quality data from Cuivre River near Troy, Missouri, 1984 and 1995. (Data source USGS, 1985 and 1996.)

MISSOURI RIVER TRIBUTARIES NORTH OF THE MISSOURI RIVER

BASIN DESCRIPTION AND HYDROGEOLOGY

The **Missouri River** drains approximately 36,537 square miles in Missouri (Vandike, 1995). Its drainage north of the river encompasses about 16,245 square miles. Glacial drift covers most of the area. Average thickness of drift is approximately 100 feet, though maximum thickness may be as much as 300 feet (Vandike, 1995). Movement of water through the glacial material is minimal, and groundwater contribution to stream flow is insignificant. Near the river in the northwestern part of the basin, loess deposits are the thickest in the state, from 10 to more than 30 feet thick. Loess provides a good base for agricultural soils, however it has high soil erosion and low infiltration rates, and streams traversing it carry more suspended sediment (DNR, 1995). Beneath the glacial deposits is Pennsylvanian-age bedrock with the exception of the south-central and southeastern parts of the basin where Mississippian-age and older rocks are present. Rolling hills are prevalent in the northern and western parts of the basin grading to gently rolling hills and nearly flat land in the south-central and southeastern region. Row crops, pasture, hay fields, and forest comprise land use.

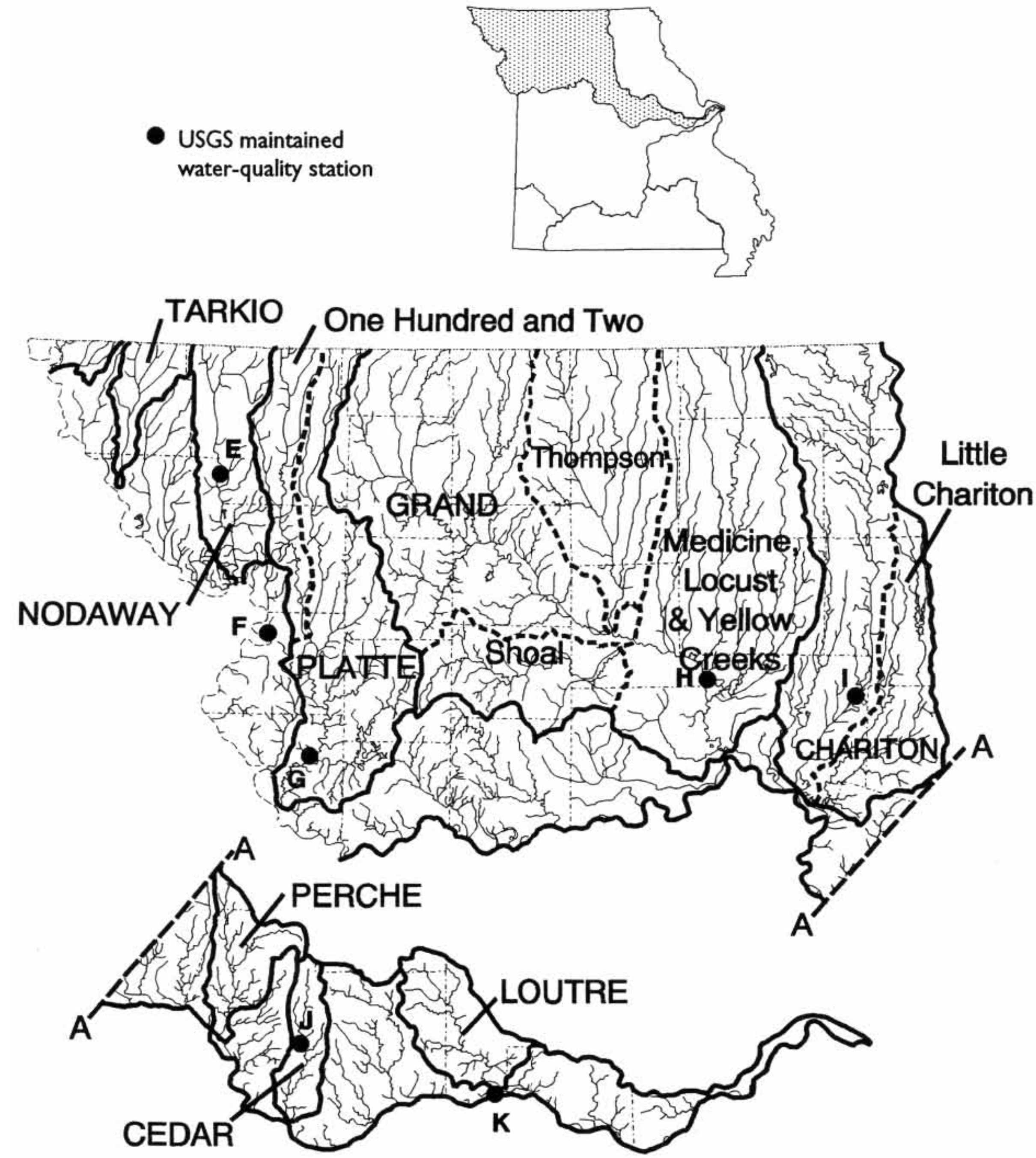
Smaller watersheds north of the river within the **Missouri River** basin include **Tarkio, Nodaway, One Hundred and Two, Platte, Grand, Thompson, Chariton, Little Chariton, and Loutre** and **Medicine, Locust, Yellow, Shoal, Perche,** and **Cedar** Creeks (figure 49).

SURFACE WATER QUALITY

Main Stem Missouri River

Water type for the **Missouri River** basin is predominantly calcium-magnesium bicarbonate, reflecting the chemistry of the rocks and soils over which it flows. Before closure of the main stem reservoirs in the 1960s, suspended-sediment concentrations in the **Missouri River** were quite high. Erosion from sparsely vegetated and arid land may have been the cause of the high concentrations early in the state's history, while agricultural practices and channelization are likely responsible for the present values (Davis and Howland, 1991.) The high surface runoff typical to this area is also partly responsible for higher concentrations of total phosphorus, total recoverable metals, fecal coliform, and fecal streptococcus bacteria. Leaching from the glacial material covering the land allows for larger concentrations of sulfate, chloride, and TDS in surface waters of this basin. Table 31 lists quarterly data from a U. S. Geological Survey water-quality station on the **Missouri River** at St. Joseph, Missouri for 1984 and 1995. Concentrations of TDS exceed the secondary drinking water standard (aesthetic) recommended MCL in three of the four seasons.

The Missouri Department of Natural Resources' list of impaired classified waters for 1996 does not include any point sources directly impacting the **Missouri River**. However, **Rush Creek**, a small tributary to the Missouri River in southern Platte County is listed with 3.9 miles of impaired waters due to high



STATION ID NO.	STATION NAME	COUNTY	DRAINAGE AREA (SQ MI)
E	Nodaway River near Graham	Holt	1,380
F	Missouri River at St. Joseph	Buchanan	420,300
G	Platte River at Sharps Station	Platte	2,380
H	Grand River near Sumner	Livingston	6,880
I	Chariton River near Prairie Hill	Chariton	1,870
J	Cedar Creek near Columbia	Boone	44.8
K	Missouri River at Herman	Montgomery	524,200

Figure 49. Missouri River tributaries north of the Missouri River

biological oxygen demand and TSS concentrations originating from a wastewater discharge. Dearborn Lake, a small reservoir located on the Buchanan-Platte County line has 7.0 acres of impaired use due to atrazine (DNR, 1996). A total of approximately 179 miles of streams in the watershed are listed as experiencing aquatic habitat loss due to channelization (DNR, 1996).

TARKIO AND NODAWAY RIVERS

The **Tarkio** and **Nodaway Rivers** drain most of Atchison, Holt, Nodaway, and Andrew Counties in extreme northwestern Missouri. Land use is predominantly agriculture and the area has population density consistent with rural locations. There are no public water supply surface water intakes or reservoirs in either basin (Vandike, 1995). A U.S. Geological Survey water-quality station is maintained on the **Nodaway River** in Holt County near Graham, Missouri. Quarterly data from this station for 1995 is given in Table 32. TDS are well within recommended Drinking Water Standards MCL, while average concentrations of manganese twice exceeded the secondary recommended limit of 50 ug/l. As expected from runoff in agricultural regions, nitrate plus nitrite as nitrogen concentration is high, ranging from 2.2 mg/l to 5.6 mg/l. Atrazine, metolachlor, and cyanazine were detected in the samples, however none of the pesticides were in concentrations above MCL. All other pesticides sampled were below detection levels. The Missouri Department of Natural Resources 1996 list of impaired waters includes numerous listings for tributaries in these basins impacted by sedimentation from agricultural runoff and habitat loss due to channelization.

PLATTE RIVER

The **One Hundred and Two** and **Little Platte Rivers** are the major tributaries to the **Platte River**. Total drainage for the **Platte River** in Missouri is 1,640 square miles (Vandike, 1995). Near its lower end, the **Little Platte River** is impounded to form Smithville Reservoir. It functions as flood control, water supply, water-quality control, recreation, and fish and wildlife enhancement. Ironically, in 1994, two acres of Smithville Reservoir were listed as impaired due to excess bacteria from waterfowl (DNR, 1994). Approximately two miles below the confluence of the Little Platte and Platte Rivers, a U.S. Geological Survey water-quality station is maintained. Table 33 shows quarterly data from this station for 1995. Drainage upstream from the station totals 2,380 square miles in Missouri and Iowa. It is interesting to note that comparison of data from this station with that from other northern Missouri stations shows dissimilar chemistry. Nitrate plus nitrite as nitrogen, sulfate, chloride, and particularly TDS are lower. Four pesticides—metolachlor, atrazine, cyanazine, and alachlor—were detected during quarterly sampling, however, none were present at concentrations exceeding MCL. Several small tributaries, and 138 miles of the **Platte River,** are on the Missouri Department of Natural Resources 1996 impaired waters list for excessive sediment due to agricultural runoff and habitat loss due to channelization. No point sources were identified in this basin.

GRAND RIVER

The **Grand River** is the largest northern tributary to the Missouri River. Its basin is approximately 150 miles long and 90 miles wide and drains all or part of 15 counties in northern Missouri (Vandike, 1995). Glacial drift, loess, and in limited areas, Pennsylvanian-age rocks form the surface of the basin. Agriculture is the predominant land use and channelization of the river to prevent flooding is extensive. Major tributaries to the **Grand River** include the **Thompson River**, **Shoal Creek, Medicine Creek, Locust Creek,** and **Yellow Creek.**

A U.S. Geological Survey water-quality station is maintained on the **Grand River** in Livingston County near Sumner, Missouri. Approximately 6,880 square miles in Missouri and Iowa drain to the river above this station. Table 34 includes quarterly water-quality data for 1984 and 1995 from samples collected at this station. Concentrations of iron and man-

CONSTITUENT	FALL 1984	FALL 1995	WINTER 1984	WINTER 1995	SPRING 1984	SPRING 1995	SUMMER 1984	SUMMER 1995
Instantaneous discharge, (ft^3/second)	53,800.	44,100	40,000	28,100	111,000	59,300	67,800	72,100
Temperature, (°Celsius)	15.0	13.5	0.5	0.5	9.0	10.0	27.0	25.5
Specific Conductance, (µs/cm)	739	711	770	690	619	710	815	810
pH, whole water, field measurement	8.3	8.3	7.8	8.8	7.9	7.9	8.2	8.4
Oxygen, dissolved (mg/l)	8.6	8.5	12.6	15.4	8.2	10.0	5.6	8.4
Fecal coliform, (colonies/100 ml)	5,700	469	2,600	280	10,000	1,270	1000	—
Fecal streptococci, (colonies/100 ml)	9,100	107	3,800	247	12,000	8,300	450	660
Alkalinity, (mg/l as $CaCO_3$)	160	164	187	210	159	207	182	193
Chloride, dissolved (mg/l)	18	19	26	20	14	18	16	18
Nitrate + ammonia total as N (mg/l)	1.2	0.8	0.7	0.6	3.5	1.7	1.3	1.7
Phosphorus, dissolved (mg/l)	0.18	0.15	0.10	0.12	1.70	0.25	0.33	0.18
Calcium, dissolved (mg/l)	65	64	73	70	66	78	75	68
Magnesium, dissolved (mg/l)	24	22	24	23	22	28	26	25
Sodium, dissolved (mg/l)	71	56	68	57	28	37	59	67
Potassium, dissolved (mg/l)	5.4	5.3	6.4	5.7	7.4	8.5	6.3	7.7
Sulfate, dissolved (mg/l)	200	160	190	160	120	170	200	210
Fluoride, dissolved (mg/l)	0.5	0.5	0.4	0.4	0.3	0.4	0.5	0.4
Total solids, dissolved (mg/l)	450	458	540	484	383	504	548	540

Table 31. Quarterly water quality data from Missouri River at St. Joseph, Missouri, 1984 and 1995. (Data source USGS, 1985 and 1996.)

CONSTITUENT	FALL	WINTER	SPRING	SUMMER
Instantaneous discharge, (ft^3/second)	146	115	1,450	1,200
Temperature, (°Celsius)	10.5	0.5	9.5	28.5
Specific Conductance, (µs/cm)	420	521	347	376
pH, whole water, field measurement	8.4	8.6	7.8	8.2
Oxygen, dissolved (mg/l)	9.4	15.4	10.2	8.2
Fecal coliform, (colonies/100 ml)	355	76	8,000	300
Fecal streptococci, (colonies/100 ml)	159	76	18,000	600
Alkalinity, (mg/l as $CaCO_3$)	171	237	133	133
Bicarbonate, dissolved (mg/l)	192	285	163	163
Nitrate + Nitrite, total as N (mg/l)	2.2	3.0	4.4	5.6
Phosphorus, dissolved (mg/l)	0.17	0.19	0.45	0.30
Calcium, dissolved (mg/l)	57	73	49	46
Magnesium, dissolved (mg/l)	15	20	14	14
Sodium, dissolved (mg/l)	10	14	9.5	9.2
Potassium, dissolved (mg/l)	2.7	3.6	2.2	2.6
Sulfate, dissolved (mg/l)	34	41	24	25
Chloride, dissolved (mg/l)	11	14	8.4	9.2
Fluoride, dissolved (mg/l)	0.2	0.3	0.3	0.3
Total solids, dissolved (mg/l)	258	338	246	230
Copper, dissolved (µg/l)	2	2	2	2
Aluminum, dissolved (µg/l)	<20	<20	20	20
Zinc, dissolved (µg/l)	5	8	16	7
Iron, dissolved (µg/l)	6	<3	3	8
Manganese, dissolved (g/l)	76	230	11	1
Atrazine, dissolved (µg/l)	0.19	0.18	1.3	0.5
Metolachlor, dissolved (µg/l)	0.19	0.12	0.18	0.12
Cyanazine, dissolved (µg/l)	0.06	0.41	0.88	0.15

Table 32. Quarterly water quality data from Nodaway River near Graham, Missouri, 1995. (Data source USGS, 1996.)

CONSTITUENT	FALL	WINTER	SPRING	SUMMER
Instantaneous discharge, (ft³/second)	585	2,430	15,200	3,030
Temperature, (°Celsius)	2.0	8.0	18.0	20.0
Specific Conductance, (µs/cm)	334	281	240	335
pH, whole water, field measurement	7.8	8.0	7.7	7.8
Oxygen, dissolved (mg/l)	11.7	12.6	6.6	7.8
Fecal coliform, (colonies/100 ml)	1,070	4,670	1,000	520
Fecal streptococci, (colonies/100 ml)	2,400	15,000	2,100	380
Alkalinity, (mg/l as $CaCO_3$)	128	108	85	142
Bicarbonate, dissolved (mg/l)	156	132	103	174
Nitrate + Nitrite, total as N (mg/l)	0.5	2.8	1.5	1.7
Phosphorus, dissolved (mg/l)	0.04	0.04	0.13	0.07
Calcium, dissolved (mg/l)	42	35	31	47
Magnesium, dissolved (mg/l)	7.9	7.5	6.0	8.3
Sodium, dissolved (mg/l)	9.2	9.7	5.0	8.2
Potassium, dissolved (mg/l)	5.2	4.0	3.6	4.0
Sulfate, dissolved (mg/l)	20	23	9	19
Chloride, dissolved (mg/l)	11.0	11.0	4.9	8.3
Fluoride, dissolved (mg/l)	0.3	0.4	0.2	0.2
Total solids, dissolved (mg/l)	189	227	146	199
Barium, dissolved (µg/l)	97	120	100	130
Aluminum, dissolved (µg/l)	60	80	<10	<10
Iron, dissolved (µg/l)	43	58	9	29
Manganese, dissolved (µg/l)	31	5	5	96
Nickel, dissolved (µg/l)	2	4	3	1
Strontium, dissolved (µg/l)	180	150	130	200
Atrazine, dissolved (µg/l)	—	--	2.6	2.7
Alachlor, dissolved (µg/l)	—	—	0.11	0.06
Cyanazine, dissolved (µg/l)	—	—	0.47	1.6

Table 33. Quarterly water quality data from Platte River at Sharps Station, Missouri, 1995. (Data source USGS, 1996.)

CONSTITUENT	FALL 1984	FALL 1995	WINTER 1984	WINTER 1995	SPRING 1984	SPRING 1995	SUMMER 1984	SUMMER 1995
Instantaneous discharge, (ft^3/second)	182	136	3,500	350	18,200	5,660	682	6,100
Temperature, (°Celsius)	15.5	10.5	0.5	0.5	9.0	13.0	32.0	27.5
Specific Conductance, (µs/cm)	450	467	438	517	261	284	483	245
pH, whole water, field measurement	8.1	8.0	7.8	7.9	7.7	8.0	8.2	7.5
Oxygen, dissolved (mg/l)	10.6	8.8	12.6	12.6	9.2	8.8	7.4	5.6
Fecal coliform, (colonies/100 ml)	340	53	2,100	51	2,200	13,500	70	970
Fecal streptococci, (colonies/100 ml)	630	64	6,100	26	5,200	23,300	220	970
Alkalinity, (mg/l as $CaCO_3$)	200	183	139	227	85	104	191	95
Bicarbonate, dissolved (mg/l)	—	225	—	268	—	126	—	113
Nitrate + Nitrite, total as N (mg/l)	<0.10	<0.02	2.5	0.80	2.1	1.3	0.4	0.6
Phosphorus, dissolved (mg/l)	0.15	0.13	0.11	0.03	0.85	0.41	0.21	0.14
Calcium, dissolved (mg/l)	66	67	57	74	37	37	71	32
Magnesium, dissolved (mg/l)	14	13	11	14	8.2	6.7	14	5.6
Sodium, dissolved (mg/l)	19	15	13	16	7.5	7.7	12	4.7
Potassium, dissolved (mg/l)	3.1	3.0	4.2	4.3	3.3	4.0	3.8	4.0
Sulfate, dissolved (mg/l)	36	35	63	52	32	28	34	15
Chloride, dissolved (mg/l)	12	12	11	13	6.1	7.8	9.1	3.6
Fluoride, dissolved (mg/l)	0.2	0.2	0.2	0.2	0.2	0.1	0.3	0.2
Total solids, dissolved (mg/l)	279	280	270	336	173	180	294	152
Barium, dissolved (µg/l)	130	94	110	120	83	95	140	94
Aluminum, dissolved (µg/l)	<10	20	60	<10	50	110	10	<10
Iron, dissolved (µg/l)	13	7	55	9	44	200	6	11
Manganese, dissolved (µg/l)	85	770	74	660	6	21	49	18
Nickel, dissolved (µg/l)	5	2	5	3	5	3	7	3
Strontium, dissolved (µg/l)	210	270	200	270	120	130	280	120

Table 34. Quarterly water quality data from Grand River near Sumner, Missouri, 1984 and 1995. (Data source USGS, 1984 and 1996.)

ganese routinely exceed secondary recommended limits for drinking water. Nitrate plus nitrite as nitrogen and TDS are somewhat less than is present in other northern Missouri streams. Fecal coliform bacteria densities often approach the Missouri Department of Natural Resources maximum of 200 colonies per 100 milliliters for whole-body contact recreational uses.

Impacts from point source discharges are not as prevalent in this basin compared to the effects of nonpoint contaminants and physical changes resulting from channelization. About 97 miles of upper **Grand River** are included on the 1996 impaired waters list for habitat loss due to channelization. In addition, there are numerous listings of impaired use for Grand River tributaries due to sedimentation caused by agricultural practices. Approximately 24 acres of Jamesport Lake in Daviess County are impacted by atrazine (DNR, 1996). In Caldwell County, **Shoal Creek** basin contains Hamilton Lake, a small lake that has 80 acres of impaired use due to high concentrations of atrazine and cyanazine. Additionally, 67 acres of Ridgeway Lake in Harrison County contain detectable levels of cyanazine. However, a summary of 1995 herbicide data showed no exceedences of drinking water standards for public water supplies from surface waters in this basin (DNR, 1995). **Thompson River** and **Locust Creek** have a combined total of 72 miles of habitat loss due to effects of channelization (DNR, 1996).

The point sources of concern in the **Grand River** basin are very large hog production facilities. Six miles of **Middle Fork Grand River** are adversely impacted by hog manure (DNR, 1996).

Chariton River

The **Chariton River** basin lies to the east of the Grand River basin and is next largest in size. Channelization in the 1920s altered its drainage so that one of its tributaries, the **Little Chariton River,** now has its own separate watershed (Vandike, 1995). Combined drainage for the **Chariton** and **Little Chariton** Rivers is approximately 2,960 square miles, of which 70 percent, or 2,070 square miles, is in Missouri. Compared to the watersheds to the west, the **Chariton River** basin is more hilly and has less farm land and more forest. Coal mining in eastern Putnam and western Adair Counties has affected surface water in that area. Minor water quality problems including mineralization and lowered pH have been attributed to erosion of the mine waste piles in the past, however reclamation of the area in the early 1990s has reduced these problems. Also, **Dark Creek** and **Sugar Creek**, two small tributaries to the **East Fork Chariton River** in northwestern Randolph County, are listed as having a total of 4 miles of impaired, classified stream use and about 9.5 miles of impaired, unclassified stream use as a result of drainage from a mined area (DNR, 1996). High levels of iron, sulfate, TDS, lowered pH, and some orange-colored iron deposits are the results of the acid mine drainage.

A U.S. Geological Survey water-quality station is maintained on the **Chariton River** in Chariton County near Prairie Hill, Missouri. Approximately 1,870 square miles drains to the river at this station. Table 35 includes quarterly data from 1984 and 1995. Comparison of the data indicates some seasonal changes in bacteria, alkalinity, sulfate, and TDS concentrations. Manganese occasionally is present in concentrations above the secondary recommended MCL of 50 ug/l.

The **Middle Fork Little Chariton River** is impounded to form Thomas Hill Reservoir in southern Macon and northern Randolph counties, while the **East Fork Little Chariton River** is impounded to form Long Branch Reservoir in Macon County. **Thomas Hill Reservoir** is a privately-owned reservoir used to supply cooling water for a coal-fired electric generating plant, public water supply and recreation. During dry periods, releases from the dam can be minimal, and most of the flow in the **Middle Fork Little Chariton River** below the dam will originate as discharge from the power plant ashpond. A 1991 whole effluent toxicity test showed the ashpond effluent to be nontoxic (DNR, 1995). **Long Branch Reservoir** is a U.S. Army Corps

CONSTITUENT	FALL 1984	FALL 1995	WINTER 1984	WINTER 1995	SPRING 1984	SPRING 1995	SUMMER 1984	SUMMER 1995
Instantaneous discharge, (ft^3/second)	266	54	400	—	1,870	2,340	1,720	1,540
Temperature, (°Celsius)	11.5	9.5	0.5	0.5	18.0	14.0	27.5	28.0
Specific Conductance, (µs/cm)	450	308	435	625	335	245	267	285
pH, whole water, field measurement	8.0	8.0	7.7	7.8	7.8	7.2	7.7	7.9
Oxygen, dissolved (mg/l)	9.2	12.6	14.0	15.1	9.4	7.9	6.8	7.2
Fecal coliform, (colonies/100 ml)	120	50	500	10	1,000	21,000	260	1,400
Fecal streptococci, (colonies/100 ml)	560	78	3,600	33	800	43,000	340	440
Alkalinity, (mg/l as $CaCO_3$)	115	130	93	217	109	70	76	101
Bicarbonate, dissolved (mg/l)	—	159	—	264	—	86	—	121
Nitrate + Nitrite, total as N (mg/l)	1.8	<0.02	1.0	0.3	1.0	1.1	1.7	0.5
Phosphorus, dissolved (mg/l)	0.08	0.05	0.09	0.03	0.06	0.42	0.35	0.07
Calcium, dissolved (mg/l)	70	46	61	89	47	44	35	22
Magnesium, dissolved (mg/l)	15	10	14	20	9.5	8.9	7.6	4.5
Sodium, dissolved (mg/l)	13	9.2	12	20	8.3	8.3	7.3	4.1
Potassium, dissolved (mg/l)	4.8	3.8	3.6	4.6	3.1	3.9	3.9	4.4
Sulfate, dissolved (mg/l)	120	73	100	120	57	43	29	15
Chloride, dissolved (mg/l)	7.8	7.1	7.5	13	5.5	5.2	6.2	3.8
Fluoride, dissolved (mg/l)	0.2	0.2	0.2	0.2	0.2	0.2	0.2	0.2
Total solids, dissolved (mg/l)	319	226	290	422	194	212	168	108
Aluminum, dissolved (µg/l)	<10	50	40	<20	30	20	40	20
Iron, dissolved (µg/l)	13	58	58	10	24	6	19	37
Manganese, dissolved (µg/l)	41	24	33	380	9	9	5	110
Lead, dissolved (µg/l)	1	<1	<1	<1	5	<1	<1	1
Zinc, dissolved (µg/l)	13	8	21	9	9	12	19	7

Table 35. Quarterly water quality data from Chariton River near Prairie Hill, Missouri, 1984 and 1995. (Data source USGS, 1985 and 1996.)

of Engineers reservoir encompassing 2,430 acres (Vandike, 1995). Its uses include flood control, recreation, water supply, and water-quality enhancement. Sampling by the Corps in 1988 detected low levels of atrazine in the reservoir. However, drinking water standards were not exceeded. Additional sampling indicates that very high levels of dissolved iron and manganese are present about 6 to 10 feet below the lake surface (DNR, 1995). Presently, all of the lake is listed as being impaired by excessive siltation caused by runoff from row cropping areas in the basin (DNR, 1996).

Perche and Cedar Creeks

Perche Creek watershed lies in Randolph, Howard, and Boone Counties. Agricultural land use is less in this basin than in other northern Missouri tributaries, totaling approximately 35 percent of the area. Forest occupies 55 percent of the area, while urban uses claim the remaining 10 percent. Several communities discharge wastewater effluent to tributaries in this basin and several of them show some levels of impact (DNR, 1995). **Perche Creek** and two small tributaries, **Bear Creek** and **Kelley Branch**, are currently included on the Missouri Department of Natural Resources 1996 impaired waters list for adverse effects from wastewater treatment effluent. Additionally, drainage from coal mining in north central Boone County has contributed large amounts of iron precipitates to the basin. Prior to reclamation of mined lands in Callaway County in the 1980s, the entire length of **Cedar Creek** suffered the effects of acid mine drainage, including occasional fish kills (DNR, 1995). Approximately 5 miles of **Cedar Creek** and **Manacle Creek,** a minor tributary, are presently listed as affected by acid mine drainage (DNR, 1996.) A water-quality station is maintained on **Cedar Creek** by the U.S. Geological Survey near Columbia, Missouri. Table 36 shows quarterly data from 1991. As expected, the mine drainage is reflected in these analyses by excessive concentrations of sulfate, iron, manganese, and TDS.

CONSTITUENT	FALL	WINTER	SPRING	SUMMER
Instantaneous discharge, (ft^3/second)	13	3.9	2.7	8.0
Temperature, (°Celsius)	8.0	0.5	13.5	25.5
Specific Conductance, (µs/cm)	644	760	903	1,230
pH, whole water, field measurement	7.2	7.3	7.0	7.1
Oxygen, dissolved (mg/l)	11.2	13.4	11.9	9.0
Alkalinity, (mg/l as $CaCO_3$)	39	44	55	37
Sulfate, dissolved (mg/l)	210	340	400	590
Chloride, dissolved (mg/l)	29	11	9	13
Total solids, suspended (mg/l)	61	32	7	10
Total solids, dissolved (mg/l)	459	579	667	1,010
Iron, dissolved (µg/l)	220	2,400	860	10
Manganese, dissolved (µg/l)	960	3,100	2,400	2,500

Table 36. Quarterly water quality data from Cedar Creek near Columbia, Missouri, 1991. (Data source USGS, 1992.)

MISSOURI RIVER TRIBUTARIES SOUTH OF THE MISSOURI RIVER

BASIN DESCRIPTION AND HYDROGEOLOGY

Missouri River tributaries south of the river drain approximately 20,292 square miles in Missouri, or about 29.1 percent of the state (Vandike, 1995). Physiography changes from west to east across this area. The western part of the area included in the Osage Plains physiographic section is characterized by plains and very gently rolling hills. Movement of water through underlying Pennsylvanian rocks is restricted, groundwater recharge to streams is minimal, and base flow of streams is very low or nonexistent during extended dry periods. Runoff and soil erosion rates are moderate to high, and most streams experience excessive sedimentation. Farther east, the tributaries to the Missouri River traverse land located in the Ozark Plateaus physiographic province. Thin soils and underlying carbonate rocks allow for rapid downward migration of precipitation and groundwater inflow to streams insures well-sustained base flows. Major watersheds in this area include **Lamine, Moreau, Osage,** and **Gasconade** Rivers. Tributaries to these rivers include **Blackwater, South Grand, Marais des Cygnes, Little Osage, Marmaton, Sac, Pomme de Terre, Niangua, Osage Fork, Big Piney,** and **Maries** Rivers, and **Roubidoux, Grand Glaize,** and **Little Piney** Creeks (figure 50).

SURFACE WATER QUALITY

Surface water type in streams draining the Osage Plains portion of this region is moderately-mineralized calcium-magnesium bicarbonate. Most constituents are consistently below recommended drinking water maximum contaminant limits. An exception to this is high chloride content in the **Blackwater River** basin caused by flow from saline springs. Streams that drain from the limestone rich Springfield Plateau physiographic section to the south generally have calcium bicarbonate type water. Water draining from the Salem Plateau physiographic section is typically calcium-magnesium bicarbonate, with higher TSS in streams from the northern and western parts of the region (Vandike, 1995).

MAIN STEM MISSOURI RIVER

The **Blue** and **Little Blue** Rivers are minor southern tributaries to the **Missouri River** in extreme western Missouri. A large percentage of the Kansas City metropolitan and suburban areas are included in these basins. Approximately half of the **Blue River** basin is in eastern Kansas. Land use there is primarily agricultural or urban. Urban land use has associated with it different contaminants than are generally found in agricultural or rural areas. A study of urban stormwater runoff in the Blue River Basin in 1981-82 showed that most of the nitrogen, phosphorus and metals found in stormwater flows in the Blue River were associated with suspended sediment contributed by rural agricultural areas. However, greater concentrations of total lead and zinc, and high levels of biological oxygen demand (BOD) and organic nitrogen,

STATION ID NO.	STATION NAME	COUNTY	DRAINAGE AREA (SQ MI)
L	Osage River above Schell City	Bates	5,410
M	E. Fork Drywood Creek at Prairie	Barton	3.5
N	Little Sac River at Walnut Grove	Greene	119
O	Pomme De Terre River near Polk	Polk	276
P	Big Buffalo Creek at Big Buffalo Wildlife Area	Morgan	24.5
Q	W. Fork Tebo Creek near Lewis	Henry	18
R	Niangua River near Windyville	Dallas	338
S	Osage River below St. Thomas	Cole	14,500
T	Big Piney River at Devil's Elbow	Pulaski	760

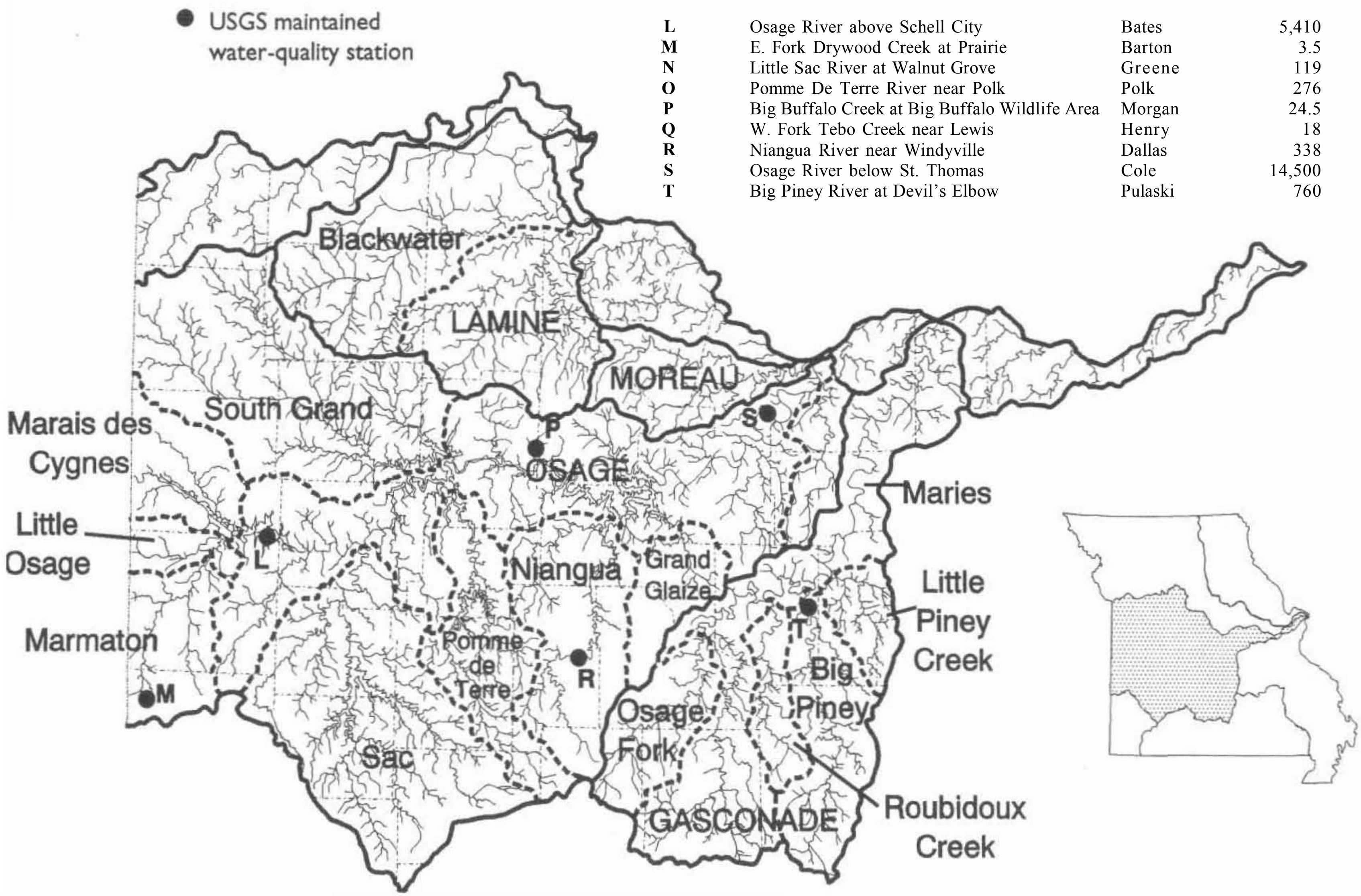


Figure 50. Missouri River tributaries south of the Missouri River.

were attributed to urban runoff (Blevins, 1986). A concerted effort has been made in recent years to eliminate all point source discharges to the **Blue River** basin (DNR, 1995). Where appropriate, discharge points were relocated so that effluents flow directly into the Missouri River. These discharges have much less impact on the large flow in the Missouri River than on smaller tributaries with less flow. The Missouri Department of Natural Resources 1996 list of impaired waters includes 33 miles of impact on the **Blue River** due to the presence of chlordane. Though chlordane use was canceled by the U. S. Environmental Protection Agency in 1988, it remains a contaminant in urban runoff.

The other major urban area on the **Missouri River** lies near its mouth at St. Louis. Water in the river there is moderately mineralized. Calcium, magnesium, sodium, bicarbonate, and sulfate are the dominant chemical constituents. Approximately 351 miles downstream from the water-quality station at St. Joseph is an additional station at Hermann, Missouri. Table 37 shows quarterly water-quality data from 1984 and 1995 for this station. Comparing values from the stations at St. Joseph and Hermann illustrates the influence of inflow from streams that are less mineralized further downstream in the basin. TDS, sulfate, and chloride concentrations decrease noticeably, as do both strains of bacteria farther downstream.

LAMINE RIVER

To the east of the Blue River Basin lies the watershed of the **Lamine River.** It drains 2,640 square miles of west-central Missouri, and its major tributary, the **Blackwater River**, drains approximately 59 percent of that area, or approximately 1,550 square miles (Vandike, 1995). The **Blackwater River** watershed is primarily within the Osage Plains physiographic section, and the eastern part of the **Lamine River** basin lies in the Springfield Plateau portion of the Ozark Plateaus physiographic province. About 65 percent of the **Lamine River** basin is row crops and pasture and the remaining 35 percent is forest. The city of Sedalia is the major urban area in the basin. As in similar agricultural settings, most streams in the watershed contain excessive sediment resulting from runoff from agricultural fields. Additionally, Concordia Lake, a public water supply lake in the **Blackwater River** basin in Lafayette County has detectable levels of atrazine (DNR, 1996). Streams in the **Blackwater River** watershed receive inflow from saline springs, and especially during low flow when little dilution occurs, these streams have water quality that is rather poor. The saline springs discharge from Mississippian or Pennsylvanian bedrock. The reason for the high salinity of the springs is that the water is thought to be sea water that became trapped when these sedimentary rocks were being formed (Miller, 1971.) High levels of chloride and sulfate can combine to elevate TDS from less than 500 mg/l to more than 30,000 mg/l. Levels of these constituents coupled with varying flow conditions determine whether the water type in the **Blackwater River** is sodium- or calcium-chloride or calcium-magnesium bicarbonate.

MOREAU RIVER

The **Moreau River** drains about 580 square miles of the Salem and Springfield Plateaus in central Missouri. Sixty percent of the area is row crops and pasture, and forty percent is forest (DNR, 1995.) It converges with the Missouri River in Cole County just east of Jefferson City, which is the basin's major urban center. Most of the tributaries within the watershed contain excessive sediment due to runoff from agricultural lands. Results from studies by Lohman and Baysinger-Daniel in the late 1980s showed that stream concentrations of total nitrogen, total phosphorus, total suspended sediment, and chlorophyll A increased in proportion to the amount of pasture and cropland in the watershed. Additionally, instream nutrient levels were more affected by point source discharges than by land use (DNR, 1995.)

CONSTITUENT	FALL		WINTER		SPRING		SUMMER	
	1984	1995	1984	1995	1984	1995	1984	1995
Instantaneous discharge, (ft^3/second)	80,100	52,300	65,400	58,200	227,000	379,000	137,000	131,000
Temperature, (°Celsius)	9.5	13.5	0.5	14.5	10	17.5	27	28
Specific Conductance, (µs/cm)	570	690	605	507	494	350	565	599
pH, whole water, field measurement	8	7.8	7.9	7.7	7.9	7.8	7.9	7.8
Oxygen, dissolved (mg/l)	11	10	13.4	8.6	6	7.1	5.8	6.3
Fecal coliform, (colonies/100 ml)	1100	267	170	200	2000	1350	1100	590
Fecal streptococci, (colonies/100 ml)	1800	860	210	400	8200	3200	200	80
Alkalinity, (mg/l as $CaCO_3$)	151	170	120	152	144	114	162	140
Bicarbonate, dissolved (mg/l)	—	207	—	185	—	140	—	171
Nitrate + Nitrite, total as N (mg/l)	1.2	0.73	1.2	2	2.5	1.2	2	1.1
Phosphorus, dissolved (mg/l)	0.07	0.07	0.06	0.11	0.11	0.05	0.14	0.08
Calcium, dissolved (mg/l)	53	63	59	55	53	43	56	59
Magnesium, dissolved (mg/l)	20	20	20	16	16	11	18	16
Sodium, dissolved (mg/l)	42	57	42	33	21	12	25	26
Potassium, dissolved (mg/l)	4.7	5.9	4.7	5.8	5.8	4.8	7.2	6.6
Sulfate, dissolved (mg/l)	130	150	120	82	89	50	110	93
Chloride, dissolved (mg/l)	14	25	20	20	12	8.8	13	16
Fluoride, dissolved (mg/l)	0.3	0.4	0.3	0.4	0.3	0.2	0.4	0.3
Total solids, dissolved (mg/l)	382	448	389	345	314	228	357	—
Barium, dissolved (µg/l)	94	89	97	85	110	99	110	120
Aluminum, dissolved (µg/l)	<10	<10	40	20	40	100	40	40
Iron, dissolved (µg/l)	16	4	11	10	49	78	17	22
Manganese, dissolved (µg/l)	5	2	8	<1	8	4	<1	2
Nickel, dissolved (µg/l)	8	2	4	2	8	2	3	2
Strontium, dissolved (µg/l)	390	470	390	370	280	200	210	330
Atrazine, dissolved (µg/l)	—	—	—	—	—	1.3	—	1.8
Alachlor, dissolved (µg/l)	—	—	—	—	—	0.05	—	0.1
Cyanazine, dissolved (µg/l)	—	—	—	—	—	0.56	—	0.4

Table 37. Quarterly water quality data from Missouri River near Hermann, Missouri, 1984 and 1995. (Data source USGS, 1985 and 1996.)

Osage River

The **Osage River** basin is the largest tributary to the Missouri River. Total drainage is approximately 15,300 square miles including eastern Kansas and western Missouri (Vandike, 1995). About 70 percent of the drainage, or 10,700 square miles, is in Missouri. The Missouri portion of the basin includes four major reservoirs, **Truman Reservoir, Lake of the Ozarks, Pomme de Terre Reservoir,** and **Stockton Reservoir**.

As the **Osage River** flows from west to east, the topography it traverses changes from Osage Plains to Ozark Plateau. The upper two-thirds of the basin drain from the Osage Plains where land use is primarily agricultural with some areas of surface and sub-surface coal mining. Table 38 shows quarterly data from 1984 and 1995 for a U.S. Geological Survey water-quality station on the **Osage River** above Schell City in Bates County, Missouri. Drainage area above this station is approximately 5,410 square miles in Missouri and Kansas. Sulfate levels are moderately high and manganese concentrations high, often exceeding recommended secondary drinking water standards. These values probably indicate runoff from the coal beds and oxidation of naturally occurring sulfide minerals in the shales over which the river flows (Davis and Howland, 1991). As the river flows east, it is impounded to form two large reservoirs; **Truman Reservoir** and **Lake of the Ozarks**. The U.S. Army Corps of Engineers maintains **Truman Reservoir** for water supply, flood control, hydropower, recreation, and fish and wildlife enhancement (Vandike, 1995). Several wastewater treatment plants in the basin discharge effluent into tributaries flowing into the reservoir causing elevated levels of fecal coliform bacteria (DNR, 1995). Additionally, the DNR 1996 list of impaired waters includes 18,500 acres of impaired use in **Truman Reservoir** due to excessive biological oxygen demand caused by flooded-terrace vegetation. Weekly average outflow from Truman Dam is approximately 450 cubic feet per second which immediately enters the upper end of **Lake of the Ozarks** (DNR, 1995). **Lake of the Ozarks,** formed by Bagnell Dam, is owned and operated by Union Electric for generation of hydropower, flood control, and recreation. Small tributaries draining to the **Lake of the Ozarks** generally originate in predominantly forested areas and some pasture and hayfields. Very little agricultural land contributes drainage directly to the lake, and agricultural erosion and sedimentation are not considered significant. However, before the construction of Truman Dam, the **Osage River** contributed significant amounts of sediment to **Lake of the Ozarks**. Algal production at the upper end of the lake was inhibited by turbidity prior to construction of Truman Dam (Jones and Novak, 1981). Discharges from septic tanks and lawn care chemicals have caused high levels of algae in some coves. In addition, bacterial contamination of lake coves has been a concern. The Lake Ozark Council of Governments conducted a study in 1984 that sampled bacteria in 22 lake coves with varying degrees of residential development. Higher density residential development produced higher densities of fecal coliform bacteria in the lake, but amounts were still within state water quality standards for whole body contact recreation (DNR, 1995). While the Osage River is a major source of water for Lake of the Ozarks, other minor tributaries also contribute water. Table 39 shows quarterly data from 1995 for a U.S. Geological Survey maintained water-quality station on **Big Buffalo Creek** at Big Buffalo Wildlife Area. Drainage area for this station is quite small, 24.5 square miles, however, the chemistry reflected in samples from this station are typical to small Ozark plateaus streams. Low levels of sulfate, manganese, and TDS confirm that the stream did not travel over Osage Plains topography.

The lower **Osage River** basin is primarily pasture and hayfields, with extensive row crops in the **Osage River** valley. Flow in the lower **Osage River** is completely controlled by outflow from Bagnell Dam, and is set at 400 cubic feet per second (DNR, 1995). Lowered dissolved oxygen levels caused by release of

CONSTITUENT	FALL 1984	FALL 1995	WINTER 1984	WINTER 1995	SPRING 1984	SPRING 1995	SUMMER 1984	SUMMER 1995
Instantaneous discharge, (ft³/second)	1,250	13,900	—	1,430	8,300	1,860	2,400	45,400
Temperature, (°Celsius)	14	7.5	1	3.5	8	14	26.5	21.5
Specific Conductance, (µs/cm)	340	243	600	544	370	663	274	276
pH, whole water, field measurement	7.3	7.3	7.5	8	7.7	7.4	7.6	7.5
Oxygen, dissolved (mg/l)	8.4	9.7	11.6	13.8	8.8	9.1	5.8	6.1
Fecal coliform, (colonies/100 ml)	1,200	5	260	124	1,200	1,620	1,000	740
Fecal streptococci, (colonies/100 ml)	5,000	7,000	430	420	1,200	430	1,300	860
Alkalinity, (mg/l as $CaCO_3$)	90	83	169	152	103	136	103	84
Bicarbonate, dissolved (mg/l)	—	102	—	182	—	166	—	103
Nitrate + Nitrite, total as N (mg/l)	1.4	0.43	2	0.37	1.6	0.23	1.3	0.64
Phosphorus, dissolved (mg/l)	0.07	—	<0.01	—	0.03	—	0.05	—
Calcium, dissolved (mg/l)	45	34	87	—	50	35	41	51
Magnesium, dissolved (mg/l)	8.1	5.1	16	—	7.8	6.2	4.8	9.2
Sodium, dissolved (mg/l)	12	5.7	21	—	12	7.1	6.6	14
Potassium, dissolved (mg/l)	4.7	3.4	2.8	—	3	3.9	3.3	3.9
Sulfate, dissolved (mg/l)	59	32	130	—	61	35	18	55
Chloride, dissolved (mg/l)	8.1	6.7	17	—	11	6.5	6	8.5
Fluoride, dissolved (mg/l)	0.2	0.1	0.2	—	0.2	0.2	0.2	0.3
Total solids, dissolved (mg/l)	221	152	416	—	246	172	162	244
Barium, dissolved (µg/l)	75	—	90	—	84	—	79	—
Aluminum, dissolved (µg/l)	130	20	10	—	30	160	50	<20
Iron, dissolved (µg/l)	93	37	8	—	26	—	41	200
Manganese, dissolved (µg/l)	44	22	160	—	79	7	4	83
Nickel, dissolved (µg/l)	6	—	15	—	4	—	<1	—
Strontium, dissolved (µg/l)	250	—	450	—	320	—	200	—

Table 38. Quarterly water quality data from Osage River above Schell City, Missouri, 1984 and 1995. (Data source USGS, 1985 and 1996.)

CONSTITUENT	FALL	WINTER	SPRING	SUMMER
Instantaneous discharge, (ft^3/second)	23	13	48	4
Temperature, (°Celsius)	9.5	1.5	13.5	22.5
Specific Conductance, (µs/cm)	333	334	244	422
pH, whole water, field measurement	8.3	7.5	7.7	7.8
Oxygen, dissolved (mg/l)	9.6	14	10.4	6.5
Fecal coliform, (colonies/100 ml)	1	5	18	4
Fecal streptococci, (colonies/100 ml)	45	500	23	42
Alkalinity, (mg/l as $CaCO_3$)	164	184	124	210
Bicarbonate, dissolved (mg/l)	200	225	154	258
Nitrate + Nitrite, total as N (mg/l)	0.08	0.07	0.02	0.1
Phosphorus, dissolved (mg/l)	0.09	<0.02	<0.02	<0.02
Calcium, dissolved (mg/l)	—	34	41	—
Magnesium, dissolved (mg/l)	—	20	24	—
Sodium, dissolved (mg/l)	—	2	2.3	—
Potassium, dissolved (mg/l)	—	0.8	1.3	—
Sulfate, dissolved (mg/l)	—	8.1	6.3	—
Chloride, dissolved (mg/l)	—	2.2	1.9	—
Fluoride, dissolved (mg/l)	—	<0.1	<0.1	—
Total solids, dissolved (mg/l)	—	174	190	—
Copper, dissolved (µg/l)	—	<1	<1	—
Aluminum, dissolved (µg/l)	—	<20	30	—
Lead, dissolved (µg/l)	—	<1	1	—
Iron, dissolved (µg/l)	—	3	3	—
Manganese, dissolved (µg/l)	—	2	5	—
Mercury, Total Recoverable (µg/l)	—	0.2	0.2	—
Zinc, dissolved (µg/l)	—	<4	5	—

Table 39. Quarterly water quality data from Big Buffalo Creek at Big Buffalo Wildlife Area, Missouri, 1995. (Data source USGS, 1996.)

poor quality hypolimnetic water from the dam are common during dry weather. The hypolimnion of a lake is the layer of water beneath the plane where temperature decreases most rapidly, 1° centigrade per meter in depth. Scour due to frequent releases of high flow has degraded the quality of aquatic habitat for several miles below the dam (DNR, 1995). Additionally, sand and gravel dredging operations disrupt aquatic habitat. Proposed changes to existing regulations regarding instream gravel mining operations should help alleviate these impacts.

About 38 miles downstream from Bagnell Dam, the U.S. Geological Survey maintains a water-quality station on the **Osage River**. The station is below St. Thomas, Missouri and receives drainage from 14,500 square miles of the Ozark Plateaus region. Table 40 lists quarterly data from 1984 and 1995 at this station. All constituents are within water quality standards, and this river is suitable for most any type of raw water usage.

South Grand River

South Grand River and its tributaries provide drainage for about 2,000 square miles of the Osage Plains in Missouri. In Henry County, Missouri, it becomes the South Grand Arm of **Truman Reservoir.** Backwater from the reservoir can affect almost half of the length of the **South Grand River** (Vandike, 1995). Agriculture is the primary land use in the watershed, and only about fifteen percent of the basin is forested. Due to high erosion rates and agricultural erosion, sediment deposition in streams should be considered a basin-wide problem (DNR, 1995.) Several hundred acres of abandoned coal mining land lies within the watershed of **Tebo Creek**, a major tributary to **South Grand River.** Table 41 shows 1991 quarterly data from a U.S. Geological Survey maintained water-quality station on W. Fork Tebo Creek near Lewis, Missouri. Mineralization resulting from runoff from mine spoils is evidenced by the high concentrations of sulfate and TDS. Additionally, iron, aluminum, and manganese are present in excessive amounts. A total of about 11.5 miles of streams in the **Tebo Creek** basin are listed by the Missouri Department of Natural Resources as being impaired by acid mine drainage (DNR, 1996).

Marais des Cygnes, Little Osage, and Marmaton Rivers

Farther south and west, the **Marais des Cygnes, Little Osage,** and **Marmaton Rivers** drain to the upper part of the **Osage River** from the Osage Plains. Land use in the upper **Osage River** basin is primarily agricultural with a mixture of row crops, pasture, and hayfields. Some coal mining also occurs in northwestern Bates and western Vernon counties. Like other prairie streams, the tributaries in this region contain relatively high amounts of sediment and have low base flows during dry periods. **Mulberry Creek**, a tributary to the **Marais des Cygnes River** and Second Nicholson Creek, a **Marmaton River** tributary are included on the 1996 list of impaired waters due to drainage from abandoned coal mine lands. Very high sulfate and TDS concentrations are found in the affected reaches. Additionally, there are numerous listings of impaired use as a result of excessive sediment from agricultural runoff.

Table 42 lists quarterly water-quality data from East Fork Drywood Creek in Barton County, Missouri, at Prairie State Park. Total drainage to this water-quality station is quite small, approximately 3.5 square miles, and abandoned mine drainage effects are not reflected in samples from this station in 1995.

Sac River

The **Sac River** and its tributaries drain approximately 1,970 square miles, the majority of which is within the Ozark plateaus physiographic province (Vandike, 1995). Drainage is generally to the north and the river eventually becomes the Sac Arm of **Truman Reservoir** in central St. Clair County. The upper part of the watershed is approximately 55 percent row crop and pasture and 45 percent forest. Infiltration of precipitation is fairly rapid and soil erosion rates are relatively low, therefore agricultural erosion and sedimenta-

CONSTITUENT	FALL 1984	FALL 1995	WINTER 1984	WINTER 1995	SPRING 1984	SPRING 1995	SUMMER 1984	SUMMER 1995
Instantaneous discharge, (ft³/second)	20,400	12,300	6,730	21,600	35,100	52,700	2,020	31,600
Temperature, (°Celsius)	12.0	15.5	1.5	3	16.5	19	25	27.5
Specific Conductance, (µs/cm)	28	272	251	254	255	281	283	248
pH, whole water, field measurement	8	7.7	7.8	7.2	7.9	7.7	7.6	7.5
Oxygen, dissolved (mg/l)	8.2	9	12.8	12.6	9.2	9.7	6	3.9
Fecal coliform, (colonies/100 ml)	96	1	10	13	<4	1,100	39	5
Fecal streptococci, (colonies/100 ml)	220	475	52	115	80	1,260	22	205
Alkalinity, (mg/l as $CaCO_3$)	106	102	106	83	91	105	123	90
Bicarbonate, dissolved (mg/l)	—	125	—	99	—	126	—	109
Nitrate + Nitrite, total as N (mg/l)	0.33	0.12	0.56	0.47	0.8	0.24	0.45	0.17
Phosphorus, dissolved (mg/l)	0.01	0.03	0.02	0.03	<0.02	0.09	0.02	0.02
Calcium, dissolved (mg/l)	39	.4	37	33	33	34	40	34
Magnesium, dissolved (mg/l)	11	9.8	11	7.9	7.7	10	8.8	6.9
Sodium, dissolved (mg/l)	5.5	4.3	5.2	5.7	7.9	4.5	5.4	8.2
Potassium, dissolved (mg/l)	2.9	2.8	3.2	3.4	2.4	2.3	2.6	3.2
Sulfate, dissolved (mg/l)	26	18	27	22	29	20	26	17
Chloride, dissolved (mg/l)	5.2	8.9	6.3	8.4	5.1	5.4	4.9	3.7
Fluoride, dissolved (mg/l)	0.1	0.1	0.1	0.1	0.1	<0.1	0.2	0.1
Total solids, dissolved (mg/l)	159	155	170	216	159	158	153	142
Barium, dissolved (µg/l)	78	67	71	60	57	61	71	51
Aluminum, dissolved (µg/l)	<10	<10	30	—	20	80	20	—
Iron, dissolved (µg/l)	14	6	21	13	18	93	9	<3
Manganese, dissolved (µg/l)	8	6	8	69	6	7	22	6
Nickel, dissolved (µg/l)	11	<1	4	<1	<1	<1	10	1
Strontium, dissolved (µg/l)	120	97	110	89	110	83	130	120

Table 40. Quarterly water quality data from Osage River near St. Thomas, Missouri, 1984 and 1995. (Data source USGS, 1985 and 1996.)

CONSTITUENT	FALL	WINTER	SPRING	SUMMER
Instantaneous discharge, (ft^3/second)	1	1	1	0.1
Temperature, (°Celsius)	8.5	0.5	16.5	28
Specific Conductance, (µs/cm)	2,080	2,090	2,010	2,040
pH, whole water, field measurement	7.8	7.8	7.9	8
Oxygen, dissolved (mg/l)	10.4	10	7.8	10.1
Fecal coliform, (colonies/100 ml)	54	9	470	370
Alkalinity, (mg/l as $CaCO_3$)	188	218	198	161
Nitrate + Nitrite, total as N (mg/l)	<0.1	<0.1	<0.05	<0.05
Phosphorus, dissolved (mg/l)	0.02	0.02	0.03	0.07
Calcium, dissolved (mg/l)	330	320	300	320
Magnesium, dissolved (mg/l)	120	120	110	110
Sodium, dissolved (mg/l)	65	64	68	79
Potassium, dissolved (mg/l)	7.6	6.3	7.7	10
Sulfate, dissolved (mg/l)	1,300	1,300	1,400	1,200
Chloride, dissolved (mg/l)	8.6	5.2	4.1	7
Fluoride, dissolved (mg/l)	0.3	<0.1	0.3	0.4
Total solids, dissolved (mg/l)	2,020	2,100	1,850	2,010
Copper, dissolved (µg/l)	2	3	2	4
Aluminum, dissolved (µg/l)	70	290	160	120
Lead, total recoverable (µg/l)	1	<1	1	<1
Iron, total recoverable (µg/l)	160	140	280	170
Manganese, total recoverable (µg/l)	370	520	250	430
Chromium, total recoverable (µg/l)	1	5	1	3
Zinc, total recoverable (µµg/l)	<10	20	<10	<10

Table 41. Quarterly water quality data from W. Fork Tebo Creek near Lewis, Missouri, 1991. (Data source USGS, 1992.)

CONSTITUENT	FALL	WINTER	SPRING	SUMMER
Instantaneous discharge, (ft^3/second)	3	0.9	0.9	2
Temperature, (°Celsius)	4.5	0.5	15.5	23.5
Specific Conductance, (μs/cm)	113	149	131	120
pH, whole water, field measurement	6.7	7.2	6.9	6.7
Oxygen, dissolved (mg/l)	11.9	13.8	8.8	7.6
Fecal coliform, (colonies/100 ml)	2	8	620	192
Fecal streptococci, (colonies/100 ml)	48	16	85	204
Alkalinity, (mg/l as $CaCO_3$)	14	22	28	21
Bicarbonate, dissolved (mg/l)	17	25	32	23
Nitrate + Nitrite, total as N (mg/l)	<0.02	<0.02	<0.02	<0.02
Phosphorus, dissolved (mg/l)	0.02	0.05	0.03	0.05
Calcium, dissolved (mg/l)	—	12	—	12
Magnesium, dissolved (mg/l)	—	4.7	—	3.2
Sodium, dissolved (mg/l)	—	8.3	4.9	—
Potassium, dissolved (mg/l)	—	1.5	4	—
Sulfate, dissolved (mg/l)	—	45	25	—
Chloride, dissolved (mg/l)	—	2.8	7.6	—
Fluoride, dissolved (mg/l)	—	<0.1	<0.1	—
Total solids, dissolved (mg/l)	—	92	88	—
Total solids, suspended (mg/l)	—	14	14	—
Aluminum, dissolved (μg/l)	—	<20	110	—
Lead, dissolved (μg/l)	—	<1	4	1
Iron, dissolved (μg/l)	—	42	—	280
Manganese, dissolved (μg/l)	—	14	—	7
Zinc, dissolved (μg/l)	—	6	—	10
Copper, dissolved (μg/l)	—	2	—	9
Atrazine, dissolved (μg/l)	—	—	0.01	—
Metolachlor, dissolved (μg/l)	—	—	0.004	—

Table 42. Quarterly water quality data from East Fork Drywood Creek at Prairie State Park, Missouri, 1995. (Data source USGS, 1996.)

tion are not considered a basin wide problem (DNR, 1995). The largest reservoir in the upper **Sac River** watershed is **Stockton Lake.** Maintained by the U.S. Army Corps of Engineers, **Stockton Lake** is used for flood control, hydroelectric power, recreation, and most recently, water supply. Compilation of water quality data from **Stockton Lake** for 1991 to 1995 shows that the average concentration of total phosphorus at the surface of the lake is 27 ug/l and chlorophyll A averaged 16 ug/l. Chloride concentrations in samples taken at the surface ranged from 6 to 10 mg/l with an average of 8 mg/l. Sulfate levels from the same sampling site ranged from 7 to 12 mg/l, averaging 9 mg/l over the 5-year period (Youngsteadt and Gumucio, 1996).

A major tributary of the **Sac River** is **Little Sac River**. From its headwaters to its confluence with **Stockton Lake** its length measures about 25 miles. Land use in the basin is 50 percent row crops and pasture, 45 percent forest, and 5 percent urban (DNR, 1995). Thin soils and fairly rapid infiltration of precipitation help limit sediment transport and contaminants from agricultural runoff are not considered a significant problem. Table 43 shows quarterly data from 1984 and 1995 for a water-quality station on the **Little Sac River** at Walnut Grove, Missouri. Though trends in water quality cannot be inferred from only two years data, comparison of the data is interesting. Nitrate plus nitrite as nitrogen and phosphorus concentrations were less during 1995. These two nutrients are typically associated with wastewater effluent, and a decrease in concentration over time might be attributed to changes in treatment processes at Springfields northwest wastewater treatment plant (Youngsteadt, pers comm, 1996). The treatment plant discharges effluent to the **Little Sac River** upstream from this water-quality station. Concentrations of sulfate and TDS are typical for streams in the Ozark Plateaus region, and are noticeably less than amounts found in prairie streams.

Below **Stockton Lake**, minimum flows in the lower **Sac River** are controlled by releases from the reservoir, and are set at 40 cubic feet per second (DNR, 1995). Drainage to the lower reaches of the river is from the Osage Plains, and streams in this area have characteristics typical of other prairie streams. Several small coal mining operations in Cedar and Dade Counties historically have been sources of acid mine drainage to streams in this basin. Reclamation in 1989 has successfully reduced their impact. Approximately one mile of a tributary to the lower **Sac River** is listed as being impaired as a result of excessive non-filterable residue from wastewater treatment discharge (DNR, 1996). The **Sac River** becomes the **Sac Arm** of **Truman Reservoir** in south-central St. Clair County.

Pomme de Terre River

The **Pomme de Terre River** basin lies to the east of the **Sac River** basin and encompasses approximately 828 square miles (Vandike, 1995). Flow is north from the Ozark Plateaus to **Truman Reservoir** in Benton County where the river becomes the **Pomme de Terre Arm** of the reservoir. In the upper part of the basin, land use is 80 percent row crops and pasture and 20 percent forest. Although the area is primarily agricultural, soil erosion rates are relatively low and agricultural erosion and runoff are not considered significant problems (DNR, 1995). Table 44 lists quarterly data from 1984 and 1995 for a U.S. Geological Survey maintained water-quality station on the **Pomme de Terre River** near Polk, Missouri. Drainage to this station comprises approximately 276 square miles. All constituents sampled are well within drinking water standards. The water is calcium-magnesium bicarbonate type and typifies water from an Ozark Plateaus stream. In Hickory County, Missouri, the **Pomme de Terre River** is impounded to form **Pomme de Terre Reservoir**. The reservoir is maintained by the U.S. Army Corps of Engineers and provides flood control and recreation. The other tributaries feeding the reservoir lie in a watershed that is 70 percent forest and 30 percent pasture and cropland. Soil erosion rates are relatively low and agricultural erosion is not considered a

CONSTITUENT	FALL 1984	FALL 1995	WINTER 1984	WINTER 1995	SPRING 1984	SPRING 1995	SUMMER 1984	SUMMER 1995
Instantaneous discharge, (ft³/second)	50	163	40	21	250	145	40	11
Temperature, (°Celsius)	10.5	8.5	2.5	4	10	12.5	25.5	23
Specific Conductance, (µs/cm)	440	456	477	618	395	286	494	1,090
pH, whole water, field measurement	7.8	8	7.9	8.1	7.8	7.9	7.8	7.9
Oxygen, dissolved (mg/l)	7.8	11.8	14	15.9	9.6	10.7	5.4	5.5
Fecal coliform, (colonies/100 ml)	190	800	2	7	24	1,200	240	170
Fecal streptococci, (colonies/100 ml)	—	430	—	13	—	150	—	230
Alkalinity, (mg/l as $CaCO_3$)	187	182	193	198	163	162	191	215
Bicarbonate, dissolved (mg/l)	—	223	—	242	—	199	—	263
Nitrate + Nitrite, total as N (mg/l)	2.9	<0.02	2.9	1.1	2	0.88	0.5	1.9
Phosphorus, dissolved (mg/l)	0.25	<0.02	0.29	0.04	0.11	0.06	0.5	0.78
Calcium, dissolved (mg/l)	74	—	79	77	61	—	72	—
Magnesium, dissolved (mg/l)	6.7	—	7	7.7	5.5	5.2	8.1	—
Sodium, dissolved (mg/l)	12	—	13	43	6.5	14	16	—
Potassium, dissolved (mg/l)	2.7	—	2.3	4.7	1.8	2.6	3.7	—
Sulfate, dissolved (mg/l)	19	—	18	26	15	9.8	19	—
Chloride, dissolved (mg/l)	17	—	21	61	11	21	17	—
Fluoride, dissolved (mg/l)	0.3	—	0.2	0.2	0.1	<0.1	0.7	—
Total solids, dissolved (mg/l)	263	—	275	346	230	246	274	—
Copper, dissolved (µg/l)	12	—	8	2	12	3	6	—
Aluminum, dissolved (µg/l)	—	—	—	40	—	260	—	—
Mercury, total recoverable (µg/l)	0.1	—	0.1	0.3	<0.1	0.1	0.3	—
Iron, dissolved (µg/l)	35	—	22	18	8	32	11	—
Manganese, dissolved (µg/l)	23	—	18	9	20	7	55	—
Lead, dissolved (µg/l)	3	—	<1	1	<1	1	<1	—
Zinc, dissolved (µg/l)	12	—	13	17	28	9	27	—

Table 43. Quarterly water quality data from Little Sac River at Walnut Grove, Missouri, 1984 and 1995. (Data source USGS, 1985 and 1996.)

CONSTITUENT	FALL 1984	FALL 1995	WINTER 1984	WINTER 1995	SPRING 1984	SPRING 1995	SUMMER 1984	SUMMER 1995
Instantaneous discharge, (ft^3/second)	275	475	114	66	481	489	74	118
Temperature, (°Celsius)	9.5	7.5	1.5	3.5	9.5	10	26	25.5
Specific Conductance, (µs/cm)	368	346	392	455	326	370	328	398
pH, whole water, field measurement	8	8.1	7.9	7.8	8	7.9	8	8.2
Oxygen, dissolved (mg/l)	9	11.3	13.6	14.4	10.4	10.8	6.4	6.6
Fecal coliform, (colonies/100 ml)	280	115	56	20	60	3,460	1,000	208
Fecal streptococci, (colonies/100 ml)	—	104	—	18	—	1,200	—	67
Alkalinity, (mg/l as $CaCO_3$)	187	146	187	194	144	106	141	183
Bicarbonate, dissolved (mg/l)	—	178	—	237	—	130	—	224
Nitrate + Nitrite, total as N (mg/l)	0.9	0.95	1.3	0.27	0.9	0.42	0.8	0.22
Phosphorus, dissolved (mg/l)	0.5	0.06	0.1	0.02	0.2	0.09	0.14	0.05
Calcium, dissolved (mg/l)	43	36	44	45	35	—	37	38
Magnesium, dissolved (mg/l)	23	19	24	26	18	17	17	27
Sodium, dissolved (mg/l)	4	4.5	4.5	5.6	3.5	3.8	3.1	5.1
Potassium, dissolved (mg/l)	3.1	3.1	1.7	1.9	1.8	3.4	4.8	3.1
Sulfate, dissolved (mg/l)	13	9.8	14	12	12	6.7	11	6.6
Chloride, dissolved (mg/l)	9.6	9.6	11	14	7.6	6.3	6.6	9.6
Fluoride, dissolved (mg/l)	<0.1	<0.1	0.1	<0.1	<0.1	<0.1	0.1	0.5
Total solids, dissolved (mg/l)	237	196	230	228	176	190	179	218
Lead, dissolved (µg/l)	1	<1	1	<1	<1	1	<1	<1
Mercury, total recoverable (µg/l)	0.1	<0.1	<0.1	0.1	0.1	0.1	0.1	0.2
Iron, dissolved (µg/l)	28	13	17	32	11	47	17	7
Manganese, dissolved (µg/l)	22	22	18	14	14	14	25	34
Zinc, dissolved (µg/l)	7	<4	15	<4	13	5	18	<4

Table 44. Quarterly water quality data from Pomme de Terre River near Polk, Missouri, 1984 and 1995. (Data source USGS, 1985 and 1996.)

basin-wide problem (DNR, 1995). There are several very small seasonal wastewater discharges in this basin, however none of them have significant impact on their receiving streams.

Flow in the **Pomme de Terre River** below the reservoir is controlled by releases from the dam. The minimum flow is currently set at 50 cubic feet per second (DNR, 1995). Until 1971 poor water quality below the reservoir was attributed to releases of poor quality hypolimnetic water from Pomme de Terre Dam. Lowered dissolved oxygen levels and odors caused by hydrogen sulfide were common in the **Pomme de Terre River** immediately below the dam. Mixing of better quality, higher strata water with the hypolimnetic water now occurs during large releases. However, there is insufficient data to document if this effort has been successful (DNR, 1995).

NIANGUA RIVER

The **Niangua River** basin lies to the east of the Pomme de Terre watershed. Land use is predominantly forest, pasture, and hay fields with limited row crops in the river valleys (DNR, 1995). Mostly carbonate rocks form the surface of the basin, and in its upper reaches, the **Niangua** is a losing stream. Most or all of its flow is lost to the subsurface during times of low-flow. Previous studies have also shown that Bennett Spring, a large spring feeding the **Niangua River**, gets some of its recharge from the adjoining **Grand Glaize River** and **Osage Fork of the Gasconade River** basins (Vandike, 1995). Because of the carbonate terrane, most tributaries in the basin either contribute to or are recharged by groundwater, thus the underlying bedrock has a significant impact on the chemistry of surface water in this basin. Spring-influenced streams in the basin historically have contained higher concentrations of nitrate plus nitrite as nitrogen, but lower levels of phosphorus and bacteria than streams with limited groundwater inflow. Table 45 lists quarterly data for 1995 from a U.S. Geological Survey maintained water-quality station on the **Niangua River** near Windyville, Missouri. Approximately 338 square miles drains to this station, which is above the confluence of the **Niangua River** and **Bennett Spring Branch**. The data indicates that the water is calcium-magnesium bicarbonate type with little nitrate, phosphorus, or bacteria. All constituents are well within drinking water standards.

GASCONADE RIVER

The **Gasconade River** basin includes approximately 3,600 square miles of the Salem Plateau section of the Ozark plateaus physiographic province. The river flows northeasterly for 250 miles to its confluence with the Missouri River near Hermann. It is the longest unimpounded river in the state (DNR, 1995). Land use is primarily forest with some cropland and pasture. The surface of the basin is comprised of carbonate rocks and losing stream segments and springs are numerous. This interaction is evidenced by the similar chemistry of groundwater and surface water. Water type is calcium-magnesium bicarbonate reflecting the carbonate rocks over which the river flows. Inflow from groundwater to streams is also demonstrated by the fact that most of its tributaries and the **Gasconade River** itself have well-sustained base flows provided by numerous springs within the watershed. Potential threats to water quality in this basin include sand and gravel mining, improper animal waste management associated with dairy operations, and municipal wastewater discharges. Major tributaries to the **Gasconade River** are **Osage Fork, Big Piney River, Roubidoux Creek** and **Little Piney Creek.**

BIG PINEY RIVER

The **Big Piney River** is the largest tributary to the Gasconade River. It drains 768 square miles of the southwestern part of the watershed (Vandike, 1995). The U.S. Geological Survey maintains a water-quality station on the **Big Piney** at Devils Elbow just a few miles upstream from its confluence with the Gasconade River. Table 46 lists quarterly data from 1984 and 1995 for this station.

CONSTITUENT	FALL	WINTER	SPRING	SUMMER
Instantaneous discharge, (ft^3/second)	88	101	123	164
Temperature, (°Celsius)	11	0.5	11.5	24.5
Specific Conductance, (µs/cm)	406	384	368	337
pH, whole water, field measurement	8	8.2	8.3	8.1
Oxygen, dissolved (mg/l)	9	14.4	9.8	6.2
Fecal coliform, (colonies/100 ml)	96	2	7	130
Fecal streptococci, (colonies/100 ml)	81	2	34	80
Alkalinity, (mg/l as $CaCO_3$)	210	189	176	171
Bicarbonate, dissolved (mg/l)	256	231	176	209
Nitrate + Nitrite, total as N (mg/l)	<0.05	0.2	<0.05	0.38
Phosphorus, dissolved (mg/l)	0.1	<0.1	0.1	0.02
Calcium, dissolved (mg/l)	42	38	38	35
Magnesium, dissolved (mg/l)	25	24	22	20
Sodium, dissolved (mg/l)	3.8	4.1	4.3	3.7
Potassium, dissolved (mg/l)	2.2	1.5	1.6	2.3
Sulfate, dissolved (mg/l)	6.6	7.3	6.2	5.1
Chloride, dissolved (mg/l)	6.8	8	8.5	6.6
Fluoride, dissolved (mg/l)	<0.1	<0.1	<0.1	<0.1
Total solids, dissolved (mg/l)	231	203	189	183
Barium, dissolved (µg/l)	74	51	62	69
Copper, dissolved (µg/l)	<1	<1	<1	<1
Lead, dissolved (µg/l)	<1	<1	<1	<1
Iron, dissolved (µg/l)	32	20	30	10
Manganese, dissolved (µg/l)	33	19	5	26
Nickel, dissolved (µg/l)	3	2	2	2
Zinc, dissolved (µg/l)	1	1	<1	1

Table 45. Quarterly water quality data from Niangua River near Windyville, Missouri, 1995. (Data source USGS, 1996.)

CONSTITUENT	FALL 1984	FALL 1995	WINTER 1984	WINTER 1995	SPRING 1984	SPRING 1995	SUMMER 1984	SUMMER 1995
Instantaneous discharge, (ft^3/second)	700	790	490	1,180	2,100	3,730	301	622
Temperature, (°Celsius)	13	9.5	3	4.5	15	16	22	22
Specific Conductance, (µs/cm)	290	297	269	259	218	211	330	273
pH, whole water, field measurement	7.6	8.08	8	7.86	7.8	7.26	7.9	7.46
Oxygen, dissolved (mg/l)	9.2	10.6	12.6	13.6	8.6	9.9	7.5	9.1
Fecal coliform, (colonies/100 ml)	120	1	6	14	46	1,000	52	28
Fecal streptococci, (colonies/100 ml)	—	26	—	25	—	540	—	20
Alkalinity, (mg/l as $CaCO_3$)	130	149	136	136	85	92	162	134
Bicarbonate, dissolved (mg/l)	—	182	—	166	—	113	—	164
Nitrate + Nitrite, total as N (mg/l)	0.69	0.65	0.55	0.63	0.37	0.2	0.3	0.23
Phosphorus, dissolved (mg/l)	<0.05	0.02	0.1	<0.02	<0.05	0.02	0.01	<0.02
Calcium, dissolved (mg/l)	33	—	33	26	22	—	35	30
Magnesium, dissolved (mg/l)	18	—	16	15	13	17	20	—
Sodium, dissolved (mg/l)	3	—	2.5	2.5	<2	2.4	2.7	—
Potassium, dissolved (mg/l)	1.7	—	<1	1.4	1.2	1.9	1.4	—
Sulfate, dissolved (mg/l)	12	—	10	6.4	22	5.3	6.1	—
Chloride, dissolved (mg/l)	4	—	4	5.2	3	3.5	3.6	—
Fluoride, dissolved (mg/l)	0.1	—	0.2	<0.1	0.1	<0.1	0.1	—
Total solids, dissolved (mg/l)	170	—	172	158	139	150	167	—
Copper, dissolved (µg/l)	<5	—	<2	<1	<5	4	2	—
Lead, dissolved (µg/l)	<5	—	<5	<1	<5	1	<1	—
Iron, dissolved (µg/l)	<20	—	<20	35	<20	17	7	—
Manganese, dissolved (µg/l)	27	—	<20	7	30	11	30	—
Mercury, total recoverable (µg/l)	<0.2	—	<0.2	0.2	<0.2	0.2	<0.1	—
Zinc, dissolved (µg/l)	12	—	<10	<4	<10	10	10	—

Table 46. Quarterly water quality data from Big Piney River near Devil's Elbow, Missouri, 1984 and 1995. (Data source USGS, 1985 and 1996.)

STATION ID NO.	STATION NAME	COUNTY	DRAINAGE AREA (SQ MI)
DD	Elk River near Tiff City	McDonald	872
EE	Center Creek near Smithfield	Jasper	303

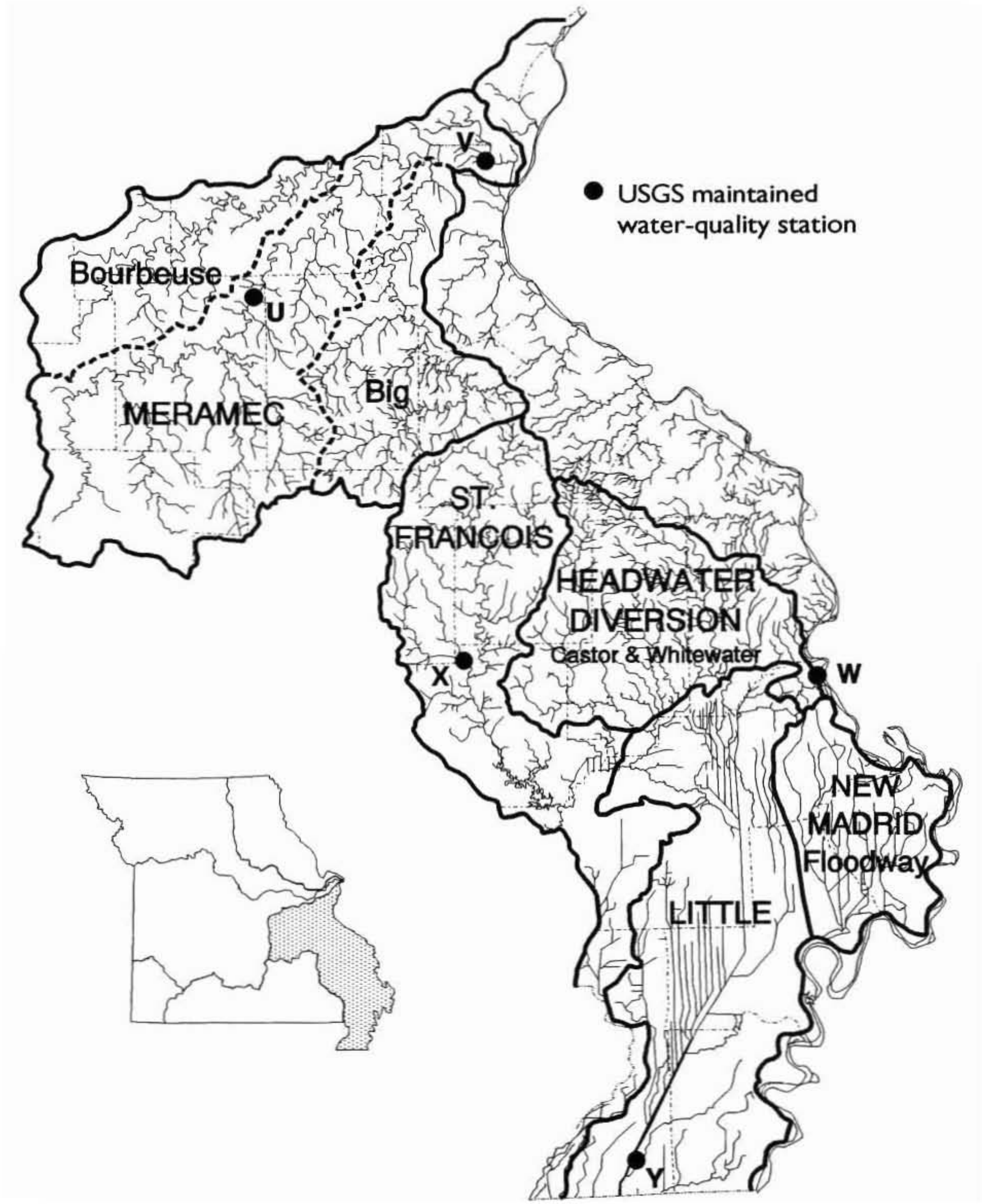


Figure 51. Lower Mississippi River tributaries in Missouri.

LOWER MISSISSIPPI RIVER TRIBUTARIES

BASIN DESCRIPTION AND HYDROGEOLOGY

In this report, the **lower Mississippi River** in Missouri is defined as that reach of the river downstream from its confluence with the Missouri River at St. Louis. It drains approximately 11,825 square miles, or 17 percent of Missouri (Vandike, 1995). The northern part of this basin is drained by the **Meramec River** which converges with the **Mississippi River** near Paulina Hills. Most of the drainage to the **Mississippi River** between the mouth of the **Meramec River** and Cape Girardeau, Missouri, is provided by small streams. West of Cape Girardeau, a complex series of man-made drainage ditches divert surface water east where it enters the **Mississippi River** just below the city. In the late 1800s this drainage system was constructed to help drain the wetlands, lower groundwater levels, and prevent future flooding in the bootheel of southeast Missouri, thereby converting previous swampland into a productive agricultural area. The **St. Francis River** basin also contributed to the flooding problems in the bootheel area, and **Wappapello Lake** was created to balance flow between high- and low-flow periods. Drainage in the bootheel area is now entirely controlled by the **Little River** drainage system which diverts all surface water to the south and west into Arkansas where it enters the **Mississippi River** (figure 51).

Three different physiographic provinces cross the lower **Mississippi River** tributaries. The northern and eastern areas are included in the Salem Plateau. The central part drains St. Francois Mountains territory, and the southern portion is an integral part of the Southeastern Lowlands. Though numerous rock types and ages appear at the surface throughout this basin, general water type for the whole watershed is calcium-magnesium bicarbonate. Land uses include agriculture, forest and urban.

SURFACE WATER QUALITY

MAIN STEM MISSISSIPPI RIVER

The main stem lower **Mississippi River** meanders a distance of about 320 miles, forming the eastern boundary of the state. Above its confluence with the Ohio River, the **Mississippi River** basin is approximately 45 percent forest, 45 percent cropland and pasture, and 10 percent urban. Major urban areas are in St. Louis and northern Jefferson counties, including the St. Louis metropolitan area, and the city of Cape Girardeau. The **Mississippi River** has many uses, including water supply, aquatic habitat, waterfowl habitat, commercial navigation, sewage disposal, recreational fishing and boating, and cooling water for power plants. Several of these uses have associated contaminants that impair part or all of other uses. For example, navigation has been improved in the river by the construction of locks and dams, and wing dikes. The result of these structures is a narrower, deeper channel that allows larger vessels. However, aquatic and wildlife habitat is impacted or lost due to these structures. Likewise, the discharge of improperly treated wastewater effluent may impact

drinking water supply, aquatic habitat, and recreational fishing and boating. Construction of treatment plants in the basin has greatly reduced the impact of wastewater on the river in the last forty years. Stormwater runoff from the St. Louis urban area contributes significant nonpoint source pollutants to the river. A 1981 study found more varieties of toxic chemicals in sewer overflows and stormwater runoff than in wastewater discharges (DNR, 1995). However, because of the large dilution capacity of the river, the impact to aquatic habitat and other uses from urban runoff is not significant.

Farther downstream, constructed drainage ditch systems divert much of the watershed to other points and the actual drainage basin supplying the lower **Mississippi** is quite narrow south of Cape Girardeau. The U.S. Geological Survey maintains a water-quality station on the **Mississippi River** at Thebes, Illinois, just south of Cape Girardeau, Missouri. Table 47 includes quarterly data from 1984 and 1995 for this station.

MERAMEC RIVER

The **Meramec River** drainage includes 3,980 square miles of the Salem Plateau (Vandike, 1995). Land use in the upper watershed is approximately 70 percent forest, 25 percent cropland and pasture, and 5 percent mined land (DNR, 1995). Carbonate rocks form the surface of most of the basin, and interaction between groundwater and surface water is extensive. There are numerous springs in the watershed that provide well-sustained base flows to streams. The U.S. Geological Survey currently maintains water-quality stations at two points along the **Meramec River**. The upstream station is located near Sullivan in Crawford County. Drainage to this station is approximately 1,475 square miles. Table 48 lists quarterly data for 1984 and 1995 at this station. The downstream station is located near Paulina Hills in Jefferson County. Drainage area above this station is 3,788 square miles, and includes water from the **Big** and **Bourbeuse** Rivers. Table 49 lists the quarterly data for 1984 and 1995 at this station. Comparison of water quality from the two stations shows the influence of lead and zinc mining activities in the **Big River** by the increased levels of sulfate, TDS, iron, manganese, and zinc in water from the downstream station near Paulina Hills. Additionally, lower dissolved oxygen (DO) concentrations and pH and higher chloride, and phosphorus and higher densities of fecal coliform bacteria in the downstream station may be the result of wastewater effluent discharges in the **Bourbeuse River** basin.

As mentioned previously, the major tributaries to the **Meramec River** are the **Big River** to the south and the **Bourbeuse River** to the north. Lead and zinc mining was prevalent in the Old Lead Belt in St. Francois County in the **Big River** basin. Runoff from mined areas has historically caused high levels of sulfate, TDS, iron, zinc, and lead in surface water. Surface mining of barite in Washington County also contributes clay fines to surface water in the basin. The Missouri Department of Natural Resources 1996 list of impaired waters includes 93 miles of stream degradation in the **Big River** caused by erosion of abandoned mine tailings.

The lower **Meramec River** basin is primarily urban, including all or parts of the south St. Louis metro communities of Arnold, Ballwin, Eureka, Fenton, Kirkwood, Manchester and Valley Park. Consistent with an urban area, the lower **Meramec** receives effluent from numerous wastewater treatment plants. Uncontrolled releases of toxic chemicals from urban areas may also affect water quality and aquatic habitat. The lower 22 miles of the **Meramec River** is known to contain fish with elevated levels of chlordane, although chlordane was canceled by the U.S. Environmental Protection Agency in 1988. During the 1980s, low levels of dioxin levels in fish were documented in the lower reaches of the river below Times Beach (DNR, 1995). Sampling for dioxin in fish tissue has not been done recently, however, DNR has been sampling for dioxin in sediment and water from the Meramec River since 1990. To date, there have been no detections of dioxin in either the sediment or water column (Long, pers comm, 1997).

CONSTITUENT	FALL 1984	FALL 1995	WINTER 1984	WINTER 1995	SPRING 1984	SPRING 1995	SUMMER 1984	SUMMER 1995
Instantaneous discharge, (ft^3/second)	215,000	145,000	133,000	95,200	521,000	855,000	358,000	251,000
Temperature, (°Celsius)	13	11	0.5	4	15	19	27	26.5
Specific Conductance, (µs/cm)	402	546	582	628	450	309	505	513
pH, whole water, field measurement	7.6	7.8	8	8.1	7.7	7.6	7.8	7.8
Oxygen, dissolved (mg/l)	7.8	9.8	6	13.8	5	6.3	6	5.5
Fecal coliform, (colonies/100 ml)	3,100	—	1,800	290	>30,000	1,200	2,100	1,000
Fecal streptococci, (colonies/100 ml)	10,000	64	2,200	300	22,000	2,100	850	280
Alkalinity, (mg/l as $CaCO_3$)	128	161	193	186	141	101	161	160
Bicarbonate, dissolved (mg/l)	—	196	—	227	—	123	—	195
Nitrate + Nitrite, total as N (mg/l)	1.4	1.66	2.5	1.87	0.06	1.8	2.8	3.5
Phosphorus, dissolved (mg/l)	0.1	0.11	0.08	0.06	0.08	0.08	0.11	0.11
Calcium, dissolved (mg/l)	41	56	58	65	50	38	56	61
Magnesium, dissolved (mg/l)	15	21	21	23	17	11	20	20
Sodium, dissolved (mg/l)	19	32	29	33	14	8.5	10	30
Potassium, dissolved (mg/l)	4	4.3	3.8	4.1	3.7	4	4.5	5.3
Sulfate, dissolved (mg/l)	56	86	78	68	64	28	61	84
Chloride, dissolved (mg/l)	15	22	29	28	15	9.7	13	20
Fluoride, dissolved (mg/l)	0.2	0.3	0.3	0.2	0.3	0.2	0.3	0.3
Total solids, dissolved (mg/l)	244	83	355	47	283	250	318	306
Barium, dissolved (µg/l)	67	70	83	74	86	70	53	110
Aluminum, dissolved (µg/l)	140	<100	20	<100	60	110	30	<100
Lead, dissolved (µg/l)	2	<5	<1	<5	2	<5	<1	<5
Iron, dissolved (µg/l)	59	<50	38	<50	49	160	54	<50
Manganese, dissolved (µg/l)	4	<15	71	19	5	<15	23	<15
Nickel, dissolved (µg/l)	5	<15	5	<15	2	<15	5	<25
Strontium, dissolved (µg/l)	190	250	230	280	180	120	320	290

Table 47. Quarterly water quality data from Mississippi River at Thebes, Illinois, 1984 and 1995. (Data source USGS, 1985 and 1996.)

CONSTITUENT	FALL 1984	FALL 1995	WINTER 1984	WINTER 1995	SPRING 1984	SPRING 1995	SUMMER 1984	SUMMER 1995
Instantaneous discharge, (ft^3/second)	810	456	740	592	1,880	3,490	496	727
Temperature, (°Celsius)	10	13	1.5	0.5	13	13.5	25	26
Specific Conductance, (µs/cm)	268	367	276	311	250	241	341	332
pH, whole water, field measurement	8	8	8.2	7.5	8.1	8	8.3	8
Oxygen, dissolved (mg/l)	10.8	11.8	14	13.4	9.6	9.8	7.8	7.1
Fecal coliform, (colonies/100 ml)	14	10	<1	2	2	230	6	55
Fecal streptococci, (colonies/100 ml)	—	6	—	5	—	110	—	47
Alkalinity, (mg/l as $CaCO_3$)	184	176	151	293	115	116	173	160
Bicarbonate, dissolved (mg/l)	—	213	—	358	—	144	—	194
Nitrate + Nitrite, total as N (mg/l)	0.08	0.02	0.43	0.17	0.28	0.18	0.3	0.26
Phosphorus, dissolved (mg/l)	<0.05	<0.02	<0.05	<0.02	<0.05	<0.02	0.01	0.02
Calcium, dissolved (mg/l)	39	37	—	37	25	—	38	38
Magnesium, dissolved (mg/l)	25	23	17	22	15	11	21	22
Sodium, dissolved (mg/l)	3.1	3.2	2.6	3	2.2	2.4	2.6	—
Potassium, dissolved (mg/l)	1.2	1.2	1.1	1	1	1.6	1.2	1.3
Sulfate, dissolved (mg/l)	7	7.7	19	8.6	12	5.9	8.2	6.6
Chloride, dissolved (mg/l)	5	15	5	6.7	3	3	3.3	3.4
Fluoride, dissolved (mg/l)	0.1	<0.1	0.1	<0.1	<0.1	<0.1	0.1	<0.1
Total solids, dissolved (mg/l)	190	202	158	<1	191	110	181	176
Lead, dissolved (µg/l)	<5	<1	<5	<1	<5	6	<1	<1
Aluminum, dissolved (µg/l)	<20	4	30	<3	30	72	6	—
Manganese, dissolved (µg/l)	<20	11	24	8	20	8	10	7
Copper, dissolved (µg/l)	<5	1	<5	2	<5	5	3	1
Zinc, dissolved (µg/l)	62	<4	<10	<4	<10	16	5	—

Table 48. Quarterly water quality data from Meramec River near Sullivan, Missouri, 1984 and 1995. (Data source USGS, 1985 and 1996.)

CONSTITUENT	FALL 1984	FALL 1995	WINTER 1984	WINTER 1995	SPRING 1984	SPRING 1995	SUMMER 1984	SUMMER 1995
Instantaneous discharge, (ft^3/second)	2,050	805	2,190	1,430	4,900	6,690	1,010	1,380
Temperature, (°Celsius)	11	13.5	0.5	3	12	14.5	28	28.5
Specific Conductance, (µs/cm)	284	471	290	342	290	241	390	394
pH, whole water, field measurement	7.8	8.4	7.9	7.6	7.9	8.2	8	7.8
Oxygen, dissolved (mg/l)	10.6	10.7	14	13.4	9	9.3	5.6	4.7
Fecal coliform, (colonies/100 ml)	240	68	270	400	44	83	100	58
Fecal streptococci, (colonies/100 ml)	—	23	—	240	—	42	—	31
Alkalinity, (mg/l as $CaCO_3$)	177	174	130	96	115	106	159	152
Bicarbonate, dissolved (mg/l)	—	202	—	117	—	132	—	185
Nitrate + Nitrite, total as N (mg/l)	0.06	0.17	0.69	0.08	0.43	0.18	0.2	0.09
Phosphorus, dissolved (mg/l)	0.13	0.09	0.1	0.03	<0.05	0.04	0.1	0.06
Calcium, dissolved (mg/l)	41	40	—	40	29	—	39	—
Magnesium, dissolved (mg/l)	27	23	15	22	15	9.4	21	20
Sodium, dissolved (mg/l)	8.4	10	7.2	7.5	4.9	3.1	7.4	—
Potassium, dissolved (mg/l)	1.7	2	1.5	1.5	1.4	2	1.9	2.1
Sulfate, dissolved (mg/l)	25	24	30	21	29	8.8	20	17
Chloride, dissolved (mg/l)	12	14	10	19	6	3.8	9.6	9
Fluoride, dissolved (mg/l)`	0.1	0.1	0.1	0.1	0.1	<0.1	0.1	<0.1
Total solids, dissolved (mg/l)	220	222	186	<1	211	110	216	172
Copper, dissolved (µg/l)	<5	2	<5	3	<5	2	3	<1
Lead, dissolved (µg/l)	<5	<1	<5	<1	<5	1	<1	<1
Iron, dissolved (µg/l)	<20	<3	60	5	30	89	6	13
Manganese, dissolved (µg/l)	27	43	51	38	50	13	200	52
Mercury, total recoverable (µg/l)	<0.2	<0.1	<0.2	<0.1	<0.2	0.3	0.1	<0.1
Zinc, dissolved (µg/l)	10	<4	13	<4	<10	6	13	<4

Table 49. Quarterly water quality data from Meramec River at Paulina Hills, Missouri, 1984 and 1995. (Data source USGS, 1985 and 1996.)

HEADWATERS DIVERSION CHANNEL

Nearly 1,200 square miles of drainage was diverted from the **St. Francis River** basin to the **Headwaters Diversion Channel** which drains east to the Mississippi River. Prior to construction of this channel, the **Castor** and **Whitewater** Rivers flowed south through the southeastern lowlands (Bootheel) and into Arkansas. To decrease flow into the Bootheel area, the **Headwaters Diversion Channel** was constructed just south of Cape Girardeau. This channel successfully diverts water formerly flowing into the **Little River** directly into the Mississippi. The basin is about 50 percent forest and 50 percent cropland and pasture, with the agricultural portion lying in the southeast corner. Typical problems associated with channelized agricultural areas occur periodically. Detection of pesticides and nitrates, increased water temperature, decreased dissolved oxygen, and channel instability all may cause degradation of aquatic habitat (DNR, 1995).

ST. FRANCIS RIVER

The **St. Francis River** drains approximately 1,700 square miles of Missouri, excluding the drainage from its tributary, the **Little River** (Vandike, 1995). Most of that area is from the Ozark Plateau including the St. Francois Mountains, where the river traverses Precambrian igneous rocks. Downward migration of water into these rocks is minimal, thus streams in the upper part of the basin receive little groundwater inflow and base flows are low during dry periods. The lower part of the basin contains Cambrian sandstones and dolomites that allow for greater interaction of groundwater and surface water, providing well-sustained base flows to streams. Table 50 lists 1995 quarterly data from a water-quality station on **Big Creek**, a tributary to **St. Francis River** at Sam A. Baker State Park. Drainage above this station is approximately 146 square miles. The chemistry of the water from this station illustrates the forested land use and igneous geology of the watershed from which the water drains. Nutrients and bacteria are low, dissolved oxygen high, and TDS are very low.

Reservoirs were constructed on the **St. Francis** and **Black** Rivers to control flow from the Ozarks to the Bootheel. In 1941, the 4,100 acre **Wappapello Lake** was created by impounding the **St. Francis River** at the junction of Wayne, Butler, and Stoddard counties. Besides the **St. Francis River** drainage, several small streams contribute water to the reservoir. Slight to moderate soil erosion in predominantly forested land restricts runoff contaminants and there are no associated nonpoint sources listed for the reservoirs drainage basin (DNR, 1995). A summary of sampling by the U.S. Army Corps of Engineers from 1987 to 1993 shows that chlorophyll A averaged 0.018 mg/l, total phosphorus averaged 0.150 mg/l and inorganic nitrogen was 0.080 mg/l. These values suggest that **Wappapello Lake** is more enriched than typical Ozark plateaus reservoirs (DNR, 1995). Flow in the **St. Francis River** below the reservoir is controlled by releases from the dam and low flows are set at about 40 cubic feet per second (DNR, 1995). Most of the lower watershed consists of alluvium in the bootheel. Ninety percent of the area is cropland and pasture with only about 10 percent forest. Soil erosion is slight to moderate mainly due to the extreme flatness of the terrain. Agricultural runoff causes some instances of pesticide contamination or low dissolved oxygen levels in surface water, however the physical changes in drainage due to channelization are considered more serious (DNR, 1995). The drainage ditch system begun in the late 1800s is made up of streambeds and banks composed of fine, unstable silts and sands that provide poor aquatic habitat and require repeated dredging (DNR, 1995).

LITTLE RIVER DITCHES

The **Little River** drainage ditch system drains a large percentage of the Bootheel. Flow in the ditches is south to the Mississippi River in Arkansas. Approximately 95 percent of the basin is cropland and pasture and only 5 percent forest. Typical agricultural runoff contaminants occur, however, their impacts are considered slight compared to the physical effects of channelization. The Missouri De-

CONSTITUENT	FALL	WINTER	SPRING	SUMMER
Instantaneous discharge, (ft^3/second)	514	374	90	140
Temperature, (°Celsius)	14	4.5	20	36.5
Specific Conductance, (µs/cm)	210	177	341	270
pH, whole water, field measurement	6.4	7.3	8	7.8
Oxygen, dissolved (mg/l)	10	13	10.6	9.2
Fecal coliform, (colonies/100 ml)	2	1	12	43
Fecal streptococci, (colonies/100 ml)	42	2	28	21
Alkalinity, (mg/l as $CaCO_3$)	68	71	115	123
Bicarbonate, dissolved (mg/l)	83	88	139	149
Nitrate + Nitrite, total as N (mg/l)	0.29	0.14	0.02	0.04
Phosphorus, dissolved (mg/l)	0.02	<0.02	<0.02	<0.02
Calcium, dissolved (mg/l)	—	16	—	26
Magnesium, dissolved (mg/l)	—	10	14	—
Sodium, dissolved (mg/l)	—	2.2	3.9	—
Potassium, dissolved (mg/l)	—	0.8	1.3	—
Sulfate, dissolved (mg/l)	—	9.7	11	—
Chloride, dissolved (mg/l)	—	4.4	5.6	—
Fluoride, dissolved (mg/l)	—	<0.1	<0.1	—
Total solids, dissolved (mg/l)	—	110	132	—
Copper, dissolved (µg/l)	—	<1	<1	—
Aluminum, dissolved (µg/l)	—	<20	30	—
Lead, dissolved (µg/l)	—	<1	1	—
Iron, dissolved (µg/l)	—	11	53	—
Manganese, dissolved (µg/l)	—	2	5	—
Mercury, total recoverable (µg/l)	—	0.1	<0.1	—
Zinc, dissolved (µg/l)	—	<4	<4	—

Table 50. Quarterly water quality data from Big Creek at Sam A. Baker State Park, Missouri, 1995. (Data source USGS, 1996.)

partment of Natural Resources 1996 list of impaired waters includes numerous listings of loss of aquatic habitat due to channelization. Channel instability, water velocities and level changes, lack of permanent riparian vegetation, and a loss of habitat diversity have all contributed to the listing of 10 species of mussels and 11 species of fish as either threatened or endangered in the Bootheel (DNR, 1995). Table 51 lists quarterly data for 1984 and 1995 from a U.S. Geological Survey-maintained water-quality station on **Little River Ditches** near Rives, Missouri. The analyses represent a composite of water from five ditches and results from this station have formerly been published as Little River Ditches near Kennett, Missouri. There is no established pattern to the chemistry from this station, and generally concentrations of certain constituents will fluctuate dramatically with differing flow conditions and seasonal variations.

NEW MARDID FLOODWAY

An additional drainage ditch system, the **New Madrid Floodway** provides drainage for eastern Scott, New Madrid, and Mississippi Counties. The major ditches channel water south to the Mississippi River just east of the town of New Madrid, Missouri. The basin lies almost entirely upon alluvium and is 90 percent cropland and pasture and 10 percent forest (DNR, 1995). Due to topographic low relief and low soil erosion rates, the impacts caused by agricultural runoff are not considered significant. Of more concern are the physical changes brought about by channelization of the area. Loss of aquatic habitat occurs frequently due to changes in water level, velocity, and temperature, instable stream beds, and insufficient riparian vegetation.

CONSTITUENT	FALL 1984	FALL 1995	WINTER 1984	WINTER 1995	SPRING 1984	SPRING 1995	SUMMER 1984	SUMMER 1995
Instantaneous discharge, (ft^3/second)	160	8,390	6,420	2,110	5,940	139	562	774
Temperature, (°Celsius)	21	15.5	2	4	12	24.5	22.5	28
Specific Conductance, (µs/cm)	401	116	105	187	132	390	335	282
pH, whole water, field measurement	7.9	7.3	6.9	7.5	7.5	8.1	7.5	7.8
Oxygen, dissolved (mg/l)	6	6.2	9	11.6	6.8	6.6	6	6.6
Fecal coliform, (colonies/100 ml)	140	4	250	520	880	—	200	240
Fecal streptococci, (colonies/100 ml)	—	250	—	1,700	—	210	—	160
Alkalinity, (mg/l as $CaCO_3$)	200	—	33	69	35	162	141	179
Bicarbonate, dissolved (mg/l)	—	194	—	81	—	202	—	120
Nitrate + Nitrite, total as N (mg/l)	<0.05	0.24	0.53	0.25	0.42	0.06	0.1	0.31
Phosphorus, dissolved (mg/l)	0.2	0.44	0.37	0.31	0.39	0.23	0.15	0.16
Calcium, dissolved (mg/l)	51	14	—	22	13	—	45	33
Magnesium, dissolved (mg/l)	15	3.9	2.8	5.8	4.2	14	12	9
Sodium, dissolved (mg/l)	15	2.9	2.9	5.1	3.5	13	11	8
Potassium, dissolved (mg/l)	2.1	6.4	2.3	3.4	2.5	2.7	2.7	3.5
Sulfate, dissolved (mg/l)	20	7.8	10	12	19	23	17	15
Chloride, dissolved (mg/l)	14	8.5	4	7.2	6	16	11	10
Fluoride, dissolved (mg/l)	0.2	0.2	0.1	0.1	0.1	0.2	0.2	0.2
Total solids, dissolved (mg/l)	250	40	72	120	180	240	206	166
Copper, dissolved (µg/l)	<5	4	<5	1	<5	<1	2	2
Lead, dissolved (µg/l)	<5	<1	6	<1	<5	1	5	1
Iron, dissolved (µg/l)	<2	120	970	48	380	32	12	57
Manganese, dissolved (µg/l)	76	24	100	48	44	26	140	20
Mercury, total recoverable (µg/l)	<0.2	0.3	<0.2	0.1	<0.2	0.1	<0.1	0.1
Zinc, dissolved (µg/l)	<10	<4	21	<4	16	<4	24	4

Table 51. Quarterly water-quality data from the Little River Ditches near Rives, Missouri, 1984 and 1995; analyses represent water composite from five ditches. (Data source USGS, 1985 and 1996.)

STATION ID NO.	STATION NAME	COUNTY	DRAINAGE AREA (SQ MI)
Z	Current River at Doniphan	Ripley	2,038
AA	Jack's Fork at Alley Spring (0.5 mile upstream of spring)	Shannon	298
BB	Bryant Creek below Evans	Douglas	214
CC	James River near Boaz	Christian	462

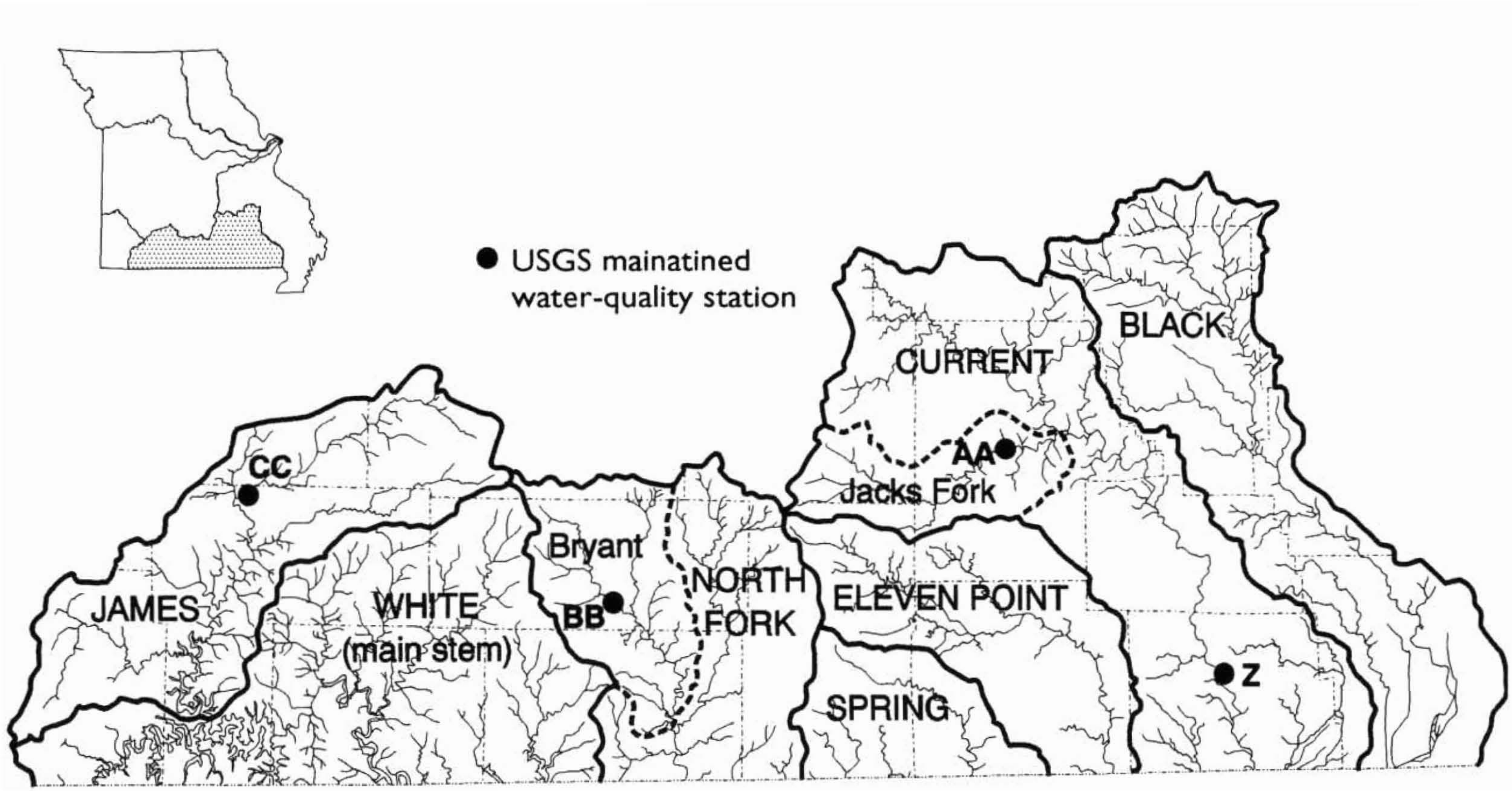


Figure 52. White River tributaties in Missouri.

WHITE RIVER TRIBUTARIES

BASIN DESCRIPTION AND HYDROGEOLOGY

The **White River** drains approximately 10,645 square miles in southern Missouri (Vandike, 1995). Virtually its entire length in Missouri is impounded forming three major reservoirs—**Table Rock Lake, Lake Taneycomo,** and **Bull Shoals Lake**. The river enters Missouri in Barry County where it is the upper reach of **Table Rock Lake**, flows east and north into **Lake Taneycomo**, and then follows a southeasterly path into the tailwaters of **Bull Shoals Lake** where it exits Missouri (Vandike, 1995). Drainage to the upper part of the watershed is primarily from the Salem Plateau section, with a small part of the Springfield Plateau included. The topography is quite rugged with steep valleys and spring-fed streams. Interaction between groundwater and surface water is extensive, and most streams are provided well-sustained base flows by numerous springs in their basins. Thus surface water quality is highly influenced by groundwater quality in this region. Surface-water type is typically calcium-magnesium bicarbonate, reflecting the chemical composition of the dolomite bedrock from which the springs flow.

Major tributaries to the **White River** include **Black, Current, Eleven Point, Spring, North Fork,** and **James** Rivers (figure 52).

SURFACE WATER QUALITY

BLACK RIVER

The **Black River** in southeastern Missouri is a major tributary to the **White River**. It drains about 1,400 square miles of the western side of the St. Francois Mountains region (Vandike, 1995). The surface of the basin varies from igneous rocks at the headwaters, to Ordovician sedimentary rocks in the lower basin. The Viburnum Trend, an active underground lead mining area, is mostly within the **Black River** basin. Mine water that is directly discharged to streams may contain elevated levels of nitrogen, which is a major component of the explosives used in the mines. Additionally, discharge from a mill pond where ore is separated from the rock by flotation is often rich in nitrogen and phosphorus, causing increased algal growth downstream of the discharge (DNR, 1995). Leachate from tailings may contain high zinc content, and manganese deposits often occur on streambeds below the tailings.

The **Black River** is impounded near Piedmont to form **Clearwater Lake**. The U.S. Army Corps of Engineers maintains this 1,650-acre lake for flood control and recreation. Flow below the reservoir is regulated to decrease flooding in the Bootheel. Previous studies indicate that metals in solution in water flowing into **Clearwater Lake** are

liberated within the reservoir, flushed out, and later precipitated as hydroxides downstream (DNR, 1995). Although several large mines discharge wastewater into the **Black River** upstream from the lake, the water quality in the reservoir does not appear to be significantly impacted (DNR, 1995).

Downstream from **Clearwater Lake,** the **Black River** flows from an Ozark Plateau setting to the Bootheel. Forest dominates the Ozark area, while row crops are prevalent in the Bootheel portion of the basin. Channelization of the lower basin has adversely affected aquatic habitat as described in the Little River and St. Francis River sections.

CURRENT RIVER

Just west of the **Black River** lies the watershed of the **Current River.** Drainage area is approximately 2,120 square miles (Vandike, 1995). In 1974, 134 miles of the **Current** and its major tributary, **Jacks Fork,** along with about 65,000 acres of adjoining land were designated as the Ozark National Scenic Riverways (Davis and Howland, 1992). This watershed is the most undeveloped basin in the Salem Plateau region, and is primarily forest. More large springs are located here than anywhere else in Missouri. Springs provide well-sustained base flow to area streams, and the quality of groundwater and surface water here is virtually identical. Table 52 includes quarterly data from a water-quality station on the **Current River** at Doniphan, Missouri. Drainage above this station is approximately 2,038 square miles. Note that both bacterial strains are present in extremely low concentrations, nutrients are virtually nonexistent, and TDS quite low. Water-quality in this basin represents conditions more pristine than elsewhere in Missouri. The major tributary to the **Current** is **Jacks Fork.** Although its drainage area is small, about 422 square miles, flow in **Jacks Fork** is high due to numerous large springs. Table 53 shows quarterly data from a water-quality station on the river at Alley Spring, Missouri. The station is approximately one-half mile upstream of the spring branch. As with the station at Doniphan, water quality is very good at this location.

ELEVEN POINT RIVER

South and west of the **Current River** watershed is the **Eleven Point River** basin. It drains about 1,000 square miles of southern Missouri and flows into the **Black River** in northeastern Arkansas. Land use in the basin is 60 percent forest and 40 percent cropland and pasture. The **Eleven Point River** above Thomasville loses a significant amount of its flow to the subsurface. This flow resurfaces farther downstream and also in the adjoining **Current River** watershed as springs. Because of extensive interaction of surface water and groundwater in this basin, surface-water quality and groundwater-quality can be expected to be nearly identical. Additionally, any contamination in the watershed, either point or nonpoint may be quickly channeled into the subsurface where groundwater could be impacted. Treated sewage effluent discharges from Willow Springs presently impact approximately 0.5 mile of the **Eleven Point River** (DNR, 1996).

SPRING RIVER

South of the **Eleven Point River** lies the Missouri portion of the **Spring River** tributaries. The **Spring River** is a major tributary to **Black River** and most of its drainage is in northeastern Arkansas. In Missouri, the **Spring River** tributaries combined drainage totals only 245 square miles (Vandike, 1995). Land use in the basin is equally divided between forest and cropland and pasture. Most of the upper part of **Warm Fork Spring River** basin contains losing streams and sinkholes, and streams generally have very low base flows during dry periods. The Missouri Department of Natural Resources 1996 list of impaired waters includes 0.3 miles of **Howell Creek**, a **Warm Fork Spring River** tributary, as being impacted by the West Plains wastewater effluent. Like other karst areas in southern Missouri, groundwater probably suffers more impact from surface contamination than does surface water.

CONSTITUENT	FALL 1984	FALL 1995	WINTER 1984	WINTER 1995	SPRING 1984	SPRING 1995	SUMMER 1984	SUMMER 1995
Instantaneous discharge, (ft^3/second)	1,590	5,110	2,350	4,260	6,500	3,330	1,750	2,100
Temperature, (°Celsius)	18.5	12	6	7.5	12	21	25	23.5
Specific Conductance, (µs/cm)	335	277	289	268	214	244	310	328
pH, whole water, field measurement	7.6	7.2	8.2	8.2	7.9	8	8	8.2
Oxygen, dissolved (mg/l)	7.6	8.8	11.2	12.5	10.1	8.3	9.8	8.7
Fecal coliform, (colonies/100 ml)	31	2	45	3	6	—	20	170
Fecal streptococci, (colonies/100 ml)	—	170	—	5	—	22	—	46
Alkalinity, (mg/l as $CaCO_3$)	184	152	175	130	104	135	167	161
Bicarbonate, dissolved (mg/l)	—	185	—	159	—	163	—	194
Nitrate + Nitrite, total as N (mg/l)	0.2	0.33	0.41	0.31	0.4	0.16	0.3	0.26
Phosphorus, dissolved (mg/l)	<0.05	<0.02	0.1	<0.02	<0.05	<0.02	<0.01	0.02
Calcium, dissolved (mg/l)	36	36	—	28	22	30	36	36
Magnesium, dissolved (mg/l)	23	18	17	16	14	17	20	21
Sodium, dissolved (mg/l)	<2	1.5	<2	1.4	<2	1.6	2	1.7
Potassium, dissolved (mg/l)	<1	1	<1	0.8	<1	1	<1	0.8
Sulfate, dissolved (mg/l)	3	3.8	<10	4	10	33.5	3.7	3.2
Chloride, dissolved (mg/l)	3	3.4	2	5.8	2	2.5	2.5	2.4
Fluoride, dissolved (mg/l)	0.1	<0.1	0.1	<0.1	<0.1	<0.1	<0.1	0.1
Total solids, dissolved (mg/l)	180	90	166	142	130	148	175	160
Barium, dissolved (µg/l)	<5	<1	<5	<1	<5	2	<1	1
Lead, dissolved (µg/l)	<5	<1	<5	<1	<5	1	7	1
Iron, dissolved (µg/l)	<20	11	<20	14	20	13	8	6
Manganese, dissolved (µg/l)	<20	7	<20	5	<20	4	14	5
Mercury, total recoverable (µg/l)	0.3	0.1	<0.2	0.1	<0.2	0.5	<0.1	0.2
Zinc, dissolved (µg/l)	15	<4	<10	<4	<10	<4	17	4

Table 52. Quarterly water quality data from Current River at Doniphan, Missouri, 1984 and 1995. (Data source USGS, 1985 and 1996.)

CONSTITUENT	FALL	WINTER	SPRING	SUMMER
Instantaneous discharge, (ft^3/second)	175	249	1,860	210
Temperature, (°Celsius)	8	5.5	15.5	21.5
Specific Conductance, (µs/cm)	296	275	300	317
pH, whole water, field measurement	8.2	8.2	8.2	8.3
Oxygen, dissolved (mg/l)	10.3	12.7	8.8	8.8
Fecal coliform, (colonies/100 ml)	2	3	1,500	20
Fecal streptococci, (colonies/100 ml)	6	7	1,000	42
Alkalinity, (mg/l as $CaCO_3$)	162	152	156	169
Bicarbonate, dissolved (mg/l)	198	186	190	206
Nitrate + Nitrite, total as N (mg/l)	0.18	0.26	0.15	0.23
Phosphorus, dissolved (mg/l)	<0.01	<0.01	<0.01	<0.01
Calcium, dissolved (mg/l)	31	30	32	34
Magnesium, dissolved (mg/l)	19	18	18	20
Sodium, dissolved (mg/l)	1.2	1.1	1.1	1.2
Potassium, dissolved (mg/l)	1.1	0.9	1.4	1.2
Sulfate, dissolved (mg/l)	3.2	3	2.3	2
Chloride, dissolved (mg/l)	1.9	1.8	2.6	1.6
Fluoride, dissolved (mg/l)	<0.1	<0.1	<0.1	<0.1
Total solids, dissolved (mg/l)	160	146	174	167
Barium, dissolved (µg/l)	26	25	30	35
Copper, dissolved (µg/l)	<1	<1	<1	<1
Lead, dissolved (µg/l)	<1	<1	<1	<1
Iron, dissolved (µg/l)	3	6	43	<3
Manganese, dissolved (µg/l)	<1	<1	4	2
Nickel, dissolved (µg/l)	2	2	1	2
Zinc, dissolved (µg/l)	<1	1	2	1

Table 53. Quarterly water quality data from Jacks Fork at Alley Spring, Missouri, 1995. (Data source USGS, 1996.)

NORTH FORK WHITE RIVER

The **North Fork White River** basin lies to the west of the **Spring River** watershed. Its major tributary, **Bryant Creek**, has a drainage basin that is nearly identical in size and hydrogeologic characteristics (Vandike, 1995). The **North Fork** watershed is 70 percent forest and 30 percent pasture and has numerous springs.

Studies have shown that water channeled into the subsurface beneath **Bryant Creek** travels northeast to the **North Fork** watershed where it emerges at Double and North Fork Springs (Vandike, 1995). Table 54 includes 1995 quarterly data from a U.S. Geological Survey maintained water-quality station on **Bryant Creek** below Evans, Missouri. Table 55 includes quarterly data from 1995 for Double Spring in the North Fork basin. Comparison of the data indicates very similar water chemistry for Double Spring and **Bryant Creek**. The **North Fork White River** drains south into **Norfork Lake** just north of the Arkansas state line. Most of the 22,000 reservoir acres is in Arkansas although the majority of drainage comes from Missouri. The lake is used for flood control, recreation, hydroelectric power generation, and drinking water (Vandike, 1995). Soil erosion rates in the lake's watershed are very low and nonpoint source contaminants are not considered a basin-wide problem (DNR, 1995).

WHITE RIVER

As previously mentioned, the entire length of the **White River** in Missouri is impounded. A discussion of its water quality is really a discussion of the water quality of each of the three reservoirs it feeds.

As the river flows northward into the Salem Plateau of Missouri, it enters the upper reaches of **Table Rock Lake**. This basin is predominantly forested with rugged hills and narrow valleys. Springs are abundant and provide much of the stream base flow during dry periods. Thus, groundwater quality highly influences surface water quality. Additionally, a wide variety of contaminants including excess sediment and agricultural chemicals, accompany development near the lake and even farther upstream in its watershed.

A summary of previous water quality sampling efforts by various agencies indicates that the greatest mean water clarity is near Table Rock Dam, and the next clearest area is the portion of the main lake upstream from the **James River** arm. High levels of nitrogen and phosphorus in the **James River** arm are due to wastewater from the Springfield, Missouri, area. Also, high levels of nitrogen but not phosphorus are present in the extreme upper part of the main lake near the Arkansas state line (DNR, 1995). As water is released from Table Rock Dam it immediately becomes **Lake Taneycomo**. Uses of this reservoir are water-supply, hydroelectric power generation, and put-and-take trout fishery. As with other stream reaches directly below dams, low dissolved oxygen (DO) is a problem. Currently, all of **Lake Taneycomo** is listed as impaired due to low DO, especially during summer and fall when levels often fall below the standard of 6 mg/l (DNR, 1996). Though the watershed of **Lake Taneycomo** is partially forested, effects from the urban area are significant. Clearing of land for development has recently caused severe erosion problems in the Branson area (DNR, 1995). Stricter state water pollution regulations now require wastewater discharges greater than 25,000 gallons per day to limit the total phosphorus concentration to no more than 0.5 mg/l in an effort to reduce algal growth in **Taneycomo** (DNR, 1995).

The third reservoir on the **White River** in Missouri is **Bull Shoals Lake**. It is the largest of the **White River** impoundments and covers approximately 43,100 acres, most of which are in Arkansas (Vandike, 1995). Its watershed is about 85 percent forest and 15 percent pasture. A summary of water analyses from 1975 to 1986 from Arkansas impoundments on the Upper White River shows that all major constituents sampled were within recommended standards with the exception of high levels of lead in water near the dam at **Bull Shoals Lake** (Arkansas Soil and Water, 1986).

CONSTITUENT	FALL	WINTER	SPRING	SUMMER
Instantaneous discharge, (ft^3/second)	285	185	197	47
Temperature, (°Celsius)	13.5	6	19.5	23
Specific Conductance, (µs/cm)	329	349	341	405
pH, whole water, field measurement	7.9	8.1	8	8.1
Oxygen, dissolved (mg/l)	9.6	16.8	10.3	8.2
Fecal coliform, (colonies/100 ml)	2	11	4,600	79
Fecal streptococci, (colonies/100 ml)	2,000	9	13,800	81
Alkalinity, (mg/l as $CaCO_3$)	176	163	181	223
Bicarbonate, dissolved (mg/l)	215	199	222	275
Nitrate + Nitrite, total as N (mg/l)	0.69	0.66	0.32	0.35
Phosphorus, dissolved (mg/l)	<0.02	<0.02	<0.02	0.05
Calcium, dissolved (mg/l)	—	38	44	47
Magnesium, dissolved (mg/l)	—	21	23	26
Sodium, dissolved (mg/l)	—	1.8	1.6	2.2
Potassium, dissolved (mg/l)	—	1.1	1.3	1.3
Sulfate, dissolved (mg/l)	—	5.1	3.5	3.5
Chloride, dissolved (mg/l)	—	4	3.1	3.5
Fluoride, dissolved (mg/l)	—	<0.1	<0.1	<0.1
Total solids, dissolved (mg/l)	—	200	200	222
Copper, dissolved (µg/l)	—	<1	<1	1
Aluminum, dissolved (µg/l)	—	<20	<20	<20
Lead, dissolved (µg/l)	—	<1	<1	<1
Iron, dissolved (µg/l)	—	<3	<3	13
Manganese, dissolved (µg/l)	—	4	4	10
Mercury, total recoverable, dissolved (µg/l)	—	0.1	0.1	<0.1
Zinc, dissolved (µg/l)	—	<4	<4	<4

Table 54. Quarterly water quality data from Bryant Creek below Evans, Missouri, 1995. (Data source USGS, 1996.)

CONSTITUENT	FALL	WINTER	SPRING	SUMMER
Instantaneous discharge, (ft^3/second)	270	210	273	109
Temperature, (°Celsius)	13	13	13.5	14
Specific Conductance, (µs/cm)	405	294	233	400
pH, whole water, field measurement	7.2	7.3	7.3	7.3
Oxygen, dissolved (mg/l)	7.2	11.5	7.8	8
Fecal coliform, (colonies/100 ml)	—	52	—	300
Fecal streptococci, (colonies/100 ml)	275	285	130	215
Alkalinity, (mg/l as $CaCO_3$)	204	134	146	240
Bicarbonate, dissolved (mg/l)	249	164	188	297
Nitrate + Nitrite, total as N (mg/l)	0.9	1.5	1	1.2
Phosphorus, dissolved (mg/l)	<0.02	0.03	<0.02	0.02
Calcium, dissolved (mg/l)	—	30	35	—
Magnesium, dissolved (mg/l)	—	17	19	—
Sodium, dissolved (mg/l)	—	2.3	2	—
Potassium, dissolved (mg/l)	—	1.7	1.9	—
Sulfate, dissolved (mg/l)	—	4.9	3.7	—
Chloride, dissolved (mg/l)	—	5.8	4.3	—
Fluoride, dissolved (mg/l)	—	<0.1	<0.1	—
Total solids, dissolved (mg/l)	—	164	160	—
Barium, dissolved (µg/l)				
Aluminum, dissolved (µg/l)	—	20	30	—
Iron, dissolved (µg/l)	—	14	11	—
Manganese, dissolved (µg/l)	—	<1	2	—
Lead, dissolved (µg/l)	—	<1	1	—
Mercury, total recoverable (µg/l)	—	0.1	<0.1	—
Zinc, dissolved (µg/l)	—	<4	4	—

Table 55. Quarterly water quality data from Double Spring near Dora, Missouri, 1995. (Data source USGS, 1996.)

JAMES RIVER

The largest and most western **White River** tributary is the **James River.** It drains about 1,460 square miles of land that is primarily located in the Springfield Plateau physiographic section. Surface-water type is calcium bicarbonate, reflecting the chemistry of the limestones underlying the basin. Land use is 63 percent agriculture (mostly pasture), 30 percent forest, and 7 percent urban. The urban area includes two-thirds of the Springfield metropolitan and much of its suburban regions. Surface-water/groundwater interaction here is extensive due to numerous losing stream reaches and sinkholes. Nonpoint contaminants associated with urban runoff can be quickly channeled into the subsurface, travel some distance underground, and resurface with little or no treatment into streams. Jordan Creek, virtually contained in the metro area, has chronic problems, including numerous fish kills due to accidental spills and releases by several industries in its watershed. **Wilson Creek**, a losing stream that is a tributary to the **James River,** receives effluent from one of Springfield's wastewater treatment plants**.** About 14 miles of **Wilson Creek** are currently listed as impaired due to effects of urban runoff (DNR, 1996). Additionally, high levels of mercury have been found in Wilson Creek that, to date, have not been linked to a particular source. A water-quality station is maintained on the **James River** about 7 miles downstream from its confluence with Wilson Creek. Table 56 lists quarterly water-quality data from 1984 and 1995 at this station.

CONSTITUENT	FALL 1984	FALL 1995	WINTER 1984	WINTER 1995	SPRING 1984	SPRING 1995	SUMMER 1984	SUMMER 1995
Instantaneous discharge, (ft^3/second)	295	324	160	2,080	2,300	516	121	76
Temperature, (°Celsius)	15	11.5	8.5	14	12.5	23	25.5	23.5
Specific Conductance, (µs/cm)	394	502	450	247	281	430	480	817
pH, whole water, field measurement	8	7.7	8.6	7.6	7.9	7.9	7.9	7.8
Oxygen, dissolved (mg/l)	8	13.3	17.2	10.2	10	9.1	6.2	6
Fecal coliform, (colonies/100 ml)	420	2	2	13,700	7,600	30	210	60
Fecal streptococci, (colonies/100 ml)	—	26	—	8,900	—	124	—	3,740
Alkalinity, (mg/l as $CaCO_3$)	154	181	160	90	118	167	147	159
Bicarbonate, dissolved (mg/l)	—	221	—	110	—	201	—	195
Nitrate + Nitrite, total as N (mg/l)	2.2	2.8	3.7	1.1	1.5	1.8	0.4	6.7
Phosphorus, dissolved (mg/l)	0.43	0.28	0.7	0.14	0.16	0.25	0.71	2.1
Calcium, dissolved (mg/l)	61	72	78	—	43	65	64	70
Magnesium, dissolved (mg/l)	7.1	6.1	6.6	—	5.8	5.7	6.2	6.3
Sodium, dissolved (mg/l)	12	20	17	—	4.2	17	21	92
Potassium, dissolved (mg/l)	3.3	2.6	2.9	—	2.1	2.9	3.4	7.1
Sulfate, dissolved (mg/l)	21	22	33	—	10	15	40	64
Chloride, dissolved (mg/l)	18	22	24	—	8.6	18	28	78
Fluoride, dissolved (mg/l)	0.1	0.2	0.2	—	<0.1	0.1	0.2	0.6
Total solids, dissolved (mg/l)	242	292	292	—	166	244	184	508
Copper, dissolved (µg/l)	4	1	1	—	2	4	3	5
Lead, dissolved (µg/l)	2	<1	<1	—	<1	3	5	2
Iron, dissolved (µg/l)	22	5	6	—	35	35	5	8
Manganese, dissolved (µg/l)	12	6	5	—	15	8	10	11
Mercury, total recoverable (µg/l)	<0.1	0.1	0.1	—	<0.1	0.5	0.1	0.1
Zinc, dissolved (µg/l)	36	<4	27	—	67	8	17	17

Table 56. Quarterly water quality data from James River near Boaz, Missouri, 1984 and 1995. (Data source USGS, 1985 and 1996.)

STATION ID NO.	STATION NAME	COUNTY	DRAINAGE AREA (SQ MI)
U	Meramec River near Sullivan	Crawford	1,475
V	Meramec River at Paulina Hills	Jefferson	3,788
W	Mississippi River at Thebes, IL	Alexander, IL	713,200
X	Big Creek at Sam A. Baker State Park	Wayne	146
Y	Little River Ditches near Rives	Dunklin	880

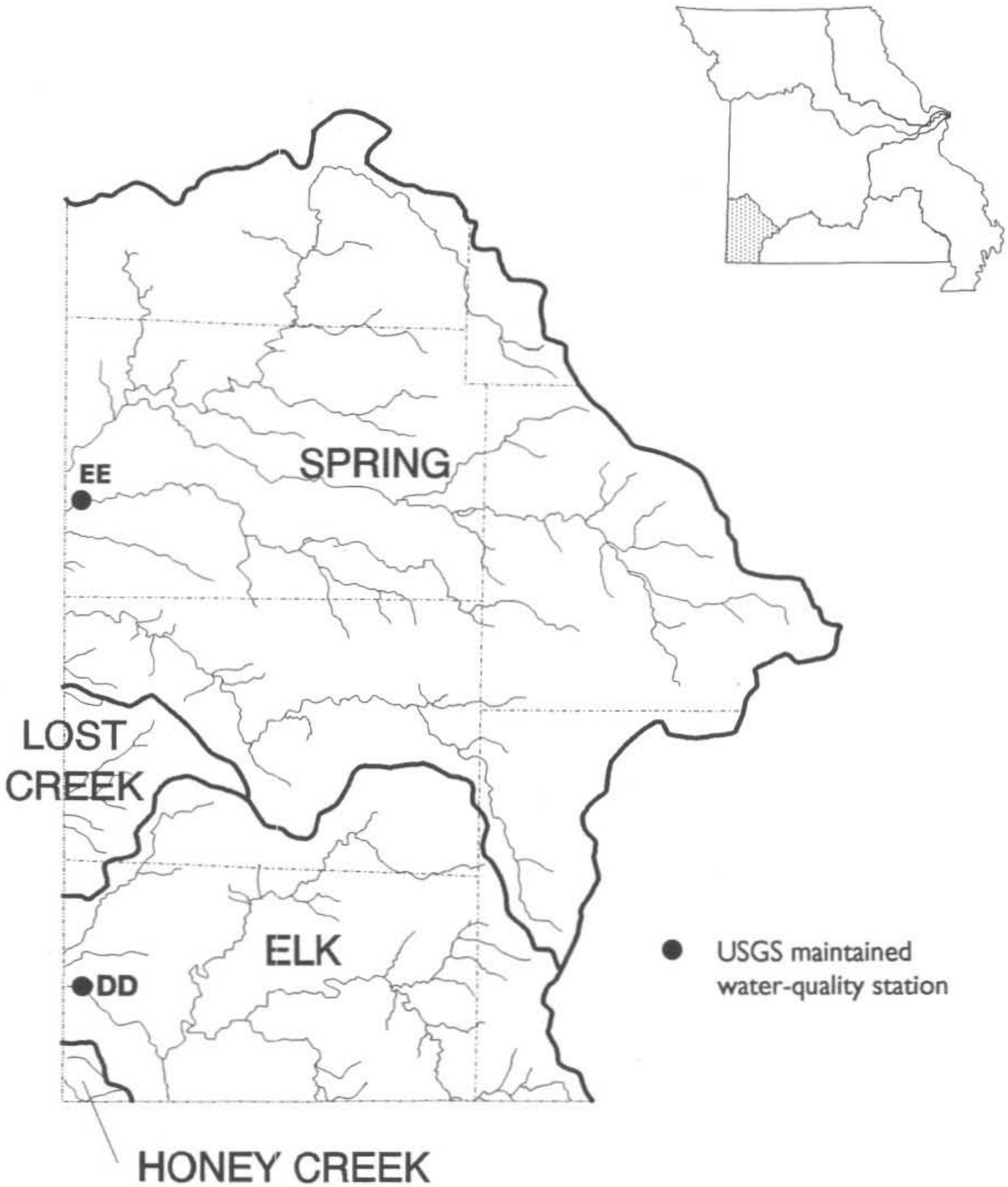


Figure 53. Arkansas River tributaries in Missouri.

ARKANSAS RIVER TRIBUTARIES

BASIN DESCRIPTION AND HYDROGEOLOGY

Tributaries to the **Arkansas River** drain approximately 2,900 square miles in Missouri (Vandike, 1995). Major tributaries are **Spring River** and **Elk River** (figure 53). Almost all of the basin is in the Springfield Plateau section where the terrain is hilly and forested. A small part of the Osage Plains in Jasper and Barton counties is included in the basin. Nearly flat agricultural land dominates the northern part of the basin. It is this northern part that was included in the Tri-State Mining District. Here subsurface zinc and lead ores were mined from the late 1800s until the 1960s, primarily around Joplin. Mine wastes, as well as industrial contaminants and municipal wastewater discharges have historically had substantial impacts on the quality of surface water in this area. Runoff into abandoned mine workings becomes more mineralized as it moves through the mined areas and eventually resurges to streams at lower elevations. High levels of zinc, sulfate, and iron are common where this has occurred. Generally, surface-water type in this basin is calcium bicarbonate, reflecting the chemistry of the limestones over which it flows. Locally, the influence of sulfide minerals can change it to calcium sulfate type (Feder et al, 1969).

SURFACE WATER QUALITY

SPRING RIVER

The largest **Arkansas River** tributary is **Spring River**. It drains about 2,000 square miles of southwestern Missouri. The northwestern part of the watershed receives drainage from the Osage Plains, while the remainder of the drainage originates on the Springfield Plateau. The basin is 70 percent cropland and pasture and 30 percent forest (DNR, 1995). The city of Joplin and surrounding suburbs is the major population center in the basin.

The **North Fork Spring River** drains the northern part of the **Spring River** watershed before converging with the **Spring River** and flowing into Kansas. In central Barton County, poor animal waste management and runoff from other agricultural land have resulted in excessive algal growths in Lamar City Lake (DNR, 1995). The lake, which is used as a water supply, has experienced recurrent taste and odor problems caused by the algae.

Farther south, drainage from the lead-zinc mined areas in the basin contains high levels of manganese, sulfate, calcium, and zinc. **Center Creek**, a tributary of **Spring River**, receives a large percentage of the drainage from the mined area and its lower 11 miles are currently listed as impaired due to high levels of zinc (DNR, 1996). Table 57 includes quarterly data from a U.S. Geological Survey-maintained water-quality station on **Center Creek** near Smithfield, Missouri. This station is several miles below the confluence of **Center Creek** and **Grove Creek**, and about one mile from the Kansas state line. Another **Spring River** tributary, **Turkey Creek**, drains the remainder of the mining area. Elevated levels of zinc dominate the impacts to **Turkey Creek**, and the lower 12 miles of its 18 Missouri miles are listed as impaired

(DNR, 1996). It also receives a large wastewater discharge from Joplin, which has resulted in high levels of suspended sediment and low dissolved oxygen content (DNR, 1995).

Major industries accompanied the development of the area's lead and zinc mines and contributed their own unique contaminants to surface water and groundwater. Currently, **Grove Creek**, a minor tributary to **Center Creek** is impaired due to high levels of ammonia originating from the wastewater discharge of an explosives manufacturing plant (DNR, 1996).

The southern part of **Spring River** watershed is drained by **Shoal Creek**. Numerous springs in the basin provide a well-sustained base flow to **Shoal Creek**. **Shoal Creek** is a source of drinking water for the cities of Joplin and Neosho and overall water quality in the creek is good with just a few localized problems. A wastewater discharge in the eastern part of the basin is responsible for sludge deposition, heavy algal growths, high levels of ammonia, and low dissolved oxygen in **Clear Creek**, a tributary to **Shoal Creek** (DNR, 1995). On the western side of the watershed, some slight effects from runoff from mined areas is evidenced by elevated concentrations of heavy metals in minor tributaries.

ELK RIVER

Another major tributary to the **Arkansas River** is **Elk River**. It drains about 850 square miles of extreme southwestern Missouri (Vandike, 1995). Land use is 35 percent cropland and pasture and 65 percent forest. Though the area is located on the Springfield Plateau, the terrain is more rugged like that of the adjoining Salem Plateau. Population in the area is low, but animal population, particularly poultry and hogs, is high. Discharges from poultry processing plants and land application of poultry litter and hog manure are major concerns in the basin. A review of water-quality data collected from 1990 to 1993 indicates a significant upward trend in total nitrogen and fecal streptococcus bacteria in waters throughout the basin and for nitrate plus nitrite as nitrogen on the **Elk River** near Tiff City (DNR, 1995). Table 58 lists quarterly data from 1984 and 1995 for the water-quality station near Tiff City. The portion of the **Elk River** watershed that lies in Arkansas has a much higher human population and contaminants associated with development may be contributing to abnormally high levels of nutrients in Missouri streams.

CONSTITUENT	FALL 1984	FALL 1995	WINTER 1984	WINTER 1995	SPRING 1984	SPRING 1995	SUMMER 1984	SUMMER 1995
Instantaneous discharge, (ft^3/second)	68	295	285	360	960	393	82	108
Temperature, (°Celsius)	16.5	8	5.5	6	10	18.5	28	24.5
Specific Conductance, (µs/cm)	509	365	440	341	293	344	460	384
pH, whole water, field measurement	7.9	7.9	7.7	8.1	7.3	8.5	8.2	8.1
Oxygen, dissolved (mg/l)	7.4	11.2	12	13.6	9.6	8.5	7.4	7.1
Fecal coliform, (colonies/100 ml)	160	380	72	9	1,100	87	18	100
Fecal streptococci, (colonies/100 ml)	—	190	—	6	—	100	—	130
Alkalinity, (mg/l as $CaCO_3$)	106	134	115	127	97	135	120	140
Bicarbonate, dissolved (mg/l)	—	164	—	155	—	165	—	171
Nitrate + Nitrite, total as N (mg/l)	13	3.8	8.8	2.8	3.4	2.1	0.2	4.3
Phosphorus, dissolved (mg/l)	0.15	0.05	0.13	<0.01	0.1	0.04	0.09	0.06
Calcium, dissolved (mg/l)	79	62	—	58	48	60	66	64
Magnesium, dissolved (mg/l)	4.7	2.9	1	2.7	2.2	2.6	3.4	3.1
Sodium, dissolved (mg/l)	17	7.4	8.9	6.3	5.2	4.8	13	9.6
Potassium, dissolved (mg/l)	2.2	1.6	1.7	1.4	1.9	1.5	1.7	1.9
Sulfate, dissolved (mg/l)	68	27	67	24	31.3	25	44	25
Chloride, dissolved (mg/l)	16	7.1	9	7.6	6	6.5	11	9.3
Fluoride, dissolved (mg/l)	0.3	<0.1	0.3	0.1	0.1	0.2	0.3	0.2
Total solids, dissolved (mg/l)	350	220	281	200	200	211	258	227
Copper, dissolved (µg/l)	<5	<1	<5	<1	<5	<1	2	<1
Lead, dissolved (µg/l)	<5	<1	<5	<1	<5	<1	<1	<1
Iron, dissolved (µg/l)	30	9	<20	12	60	10	6	<3
Manganese, dissolved (µg/l)	40	25	83	17	33	23	26	18
Mercury, total recoverable (µg/l)	<0.2	—	<0.2	—	<0.2	—	0.1	—
Zinc, dissolved (µg/l)	350	260	560	210	330	200	130	110

Table 57. Quarterly water quality data from Center Creek near Smithfield, Missouri, 1984 and 1995. (Data source USGS, 1985 and 1996.)

CONSTITUENT	FALL 1984	FALL 1995	WINTER 1984	WINTER 1995	SPRING 1984	SPRING 1995	SUMMER 1984	SUMMER 1995
Instantaneous discharge, (ft^3/second)	208	434	187	882	4,350	485	158	1,770
Temperature, (°Celsius)	15	10	3.5	5.5	10	12	28.5	19.5
Specific Conductance, (µs/cm)	284	290	280	275	229	273	290	272
pH, whole water, field measurement	7.9	8.2	7.9	8.2	7.8	8.2	8.2	8.1
Oxygen, dissolved (mg/l)	10	13.2	13.4	12.8	10.4	11.7	11.5	9.4
Fecal coliform, (colonies/100 ml)	76	45	52	25	420	3	180	40
Fecal streptococci, (colonies/100 ml)	—	7	—	35	—	86	—	49
Alkalinity, (mg/l as $CaCO_3$)	124	132	124	128	88	121	118	129
Bicarbonate, dissolved (mg/l)	—	162	—	157	—	147	—	157
Nitrate + Nitrite, total as N (mg/l)	0.88	1.7	1.6	2	1.7	1.3	0.4	1.6
Phosphorus, dissolved (mg/l)	<0.05	0.05	0.03	<0.01	0.04	0.04	0.04	0.03
Calcium, dissolved (mg/l)	—	52	51	49	39	48	49	48
Magnesium, dissolved (mg/l)	—	2.7	2.9	2.5	2.2	2.4	2.8	2.3
Sodium, dissolved (mg/l)	—	4.3	4.4	3.5	2.5	3.8	4.1	3.2
Potassium, dissolved (mg/l)	—	1.8	1.3	1.5	1.4	1.5	1.8	1.8
Sulfate, dissolved (mg/l)	—	5.7	7.8	4.1	8.1	4.7	6	4.6
Chloride, dissolved (mg/l)	—	6.1	7.9	5.6	4.5	5.3	6.3	4.1
Fluoride, dissolved (mg/l)	—	<0.1	<0.1	<0.1	<0.1	<0.1	<0.1	<0.1
Total solids, dissolved (mg/l)	—	170	175	156	132	156	151	162
Copper, dissolved (µg/l)	—	<1	1	4	2	<1	1	1
Lead, dissolved (µg/l)	—	<1	4	<1	<1	<1	<1	<1
Iron, dissolved (µg/l)	—	6	19	<3	8	4	5	4
Manganese, dissolved (µg/l)	—	<1	2	2	4	2	3	3
Mercury, total recoverable (µg/l)	—	—	<0.1	—	<0.1	—	<0.1	—
Zinc, dissolved (µg/l)	—	<1	11	17	9	1	4	5

Table 58. Quarterly water quality data from Elk River near Tiff City, Missouri, 1984 and 1995. (Data source USGS, 1985 and 1996.)

WATER QUALITY TRENDS

Dissolved oxygen, TDS, sulfate, chloride, inorganic nitrogen, total phosphorus, TSS and trace metals were evaluated for long-term trends at 15 Missouri stream locations (DNR, 1996). At least fifteen years of data from each location were analyzed, with data from 1993 as the most recent. Data from the **Grand, Nodaway, Thompson, South Fabius, Cuivre, Gasconade, Current,** and **Black** rivers showed no detectable trends. The **Missouri River** and the **Mississippi River** show declining concentrations of TSS. Reduction in soil erosion may result in this declining trend, however, similar trends are not witnessed on the interior rivers of the state (DNR, 1996).

Increasing levels of nitrate plus nitrite as nitrogen were seen in the **Missouri, Mississippi, Elk** and **Spring** rivers. Increased confined animal production and accompanying land application of manure probably cause the nitrogen increases in the **Elk** and **Spring** rivers, and a large number of point and nonpoint sources contribute to the increased nitrogen in the **Missouri** and **Mississippi** rivers (DNR, 1996).

Mining causes higher sulfate concentrations in the **Meramec River** and higher TDS in the **Spring River.** Elevated sulfate levels in the **Elk River** have not been explained, but the most recent change in land use in the basin is an increase in animal production, and runoff of animal manures may be the cause (DNR, 1996).

No detectable trends in chloride, total phosphorus, dissolved oxygen or trace metals are occurring.

CONCLUSIONS

Groundwater and surface water are used in many ways in Missouri, including recreation, fisheries, power generation, agricultural irrigation, transportation and drinking water. Maintaining good water quality is an environmental concern that is documented as early as 1907 in Missouri. In order to characterize the natural quality of surface water and groundwater, limits of some organic, inorganic, bacteriological, and radiological constituents have been determined. The Missouri Clean Water Law includes criteria pertaining to attainment of beneficial uses of groundwater and surface water, and the Missouri Safe Drinking Water Standards designate maximum contaminant levels for various constituents for public drinking water systems.

Water quality can be influenced by environmental factors such as precipitation, geology, topography, soil type, land use and water use. Groundwater quality varies regionally throughout the state, and is categorized and discussed according to groundwater province. Seven groundwater provinces have been identified using factors such as physiography, geology, hydrology, and vulnerability to contamination. These groundwater provinces are the Salem Plateau, St. Francois Mountains, Springfield Plateau, Osage Plains, Northeastern Missouri, Northwestern Missouri, and Southeastern Missouri (Bootheel), including Mississippi and Missouri river alluvial valleys.

Most groundwater in Missouri is good quality and constituents are generally below Drinking Water standards. Water types vary regionally in response to differing host rock chemistry. Locally, high values of sulfate, chloride, or sodium can cause the quality to become marginal. Pesticides and excess nutrients have been detected at very low concentrations in wells utilizing both shallow and deep groundwater in agricultural regions. Localized contamination of groundwater near mining areas is evident.

Geology, soils, land use, and land cover influence surface-water quality. Calcium, magnesium, sulfate, chloride, bicarbonate, silica, iron, sodium, and potassium may all be found in varying concentrations in surface water. Various strains of bacteria are present in virtually all surface water. However, the single most important influence on surface water-quality is volume of flow in the stream or river. During high flow periods, concentrations of suspended solids in streams are generally higher throughout the state. Likewise, streams traversing the agricultural parts of the state, particularly where row cropping occurs, contain higher levels of nutrients and pesticides than streams in other regions. Wastewater discharges and agricultural runoff contribute to higher densities of bacteria. Most land uses have accompanying potential contaminants specific to the use. Point sources, such as wastewater treatment plant discharges or nonpoint sources like runoff from an agricultural field, have the potential to affect surface water instantly and for long periods of time.

All of Missouri is drained either directly or indirectly by the Mississippi River and its tributaries. Major river systems contributing drainage to the Mississippi River are the Missouri River, Arkansas River, and the White River. Further delineations of these basins are 1) upper Mississippi River and its tributaries, 2) Missouri River tributaries north of the Missouri River, 3) Missouri River tributaries south of the Missouri River, 4) lower Mississippi River and its tributaries, 5) White River tributaries, and 6) Arkansas River tributaries.

Long-term trend analysis of surface water quality of Missouri's larger rivers indicates a decrease in suspended solids in the Missouri and Mississippi rivers over the last 15 to 20 years, although no corresponding trend is detectable in interior rivers. Increasing levels of nitrate plus nitrite as nitrogen are evident in the Missouri, Mississippi, Elk, and Spring rivers. Higher sulfate concentrations in the Meramec, Spring, and Elk rivers are apparent. No detectable trends in chloride, total phosphorus, dissolved oxygen, or trace metals are occurring.

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APPENDIX A

CLEAN WATER COMMISSION CRITERIA FOR DESIGNATED USES

TABLE A - CRITERIA FOR DESIGNATED USES

I = Protection of Aquatic Life
II = Human Health Protection - Fish Consumption
III = Drinking Water Supply
IV = Irrigation
V = Livestock, Wildlife Watering
VI = Whole-Body-Contact Recreation
VII = Groundwater

Pollutant (g/l)	**I**	**II**	**III**	**IV**	**V**	**VI**	**VII**
Chlorine (total residual)							
cold-water	2						
warm-water chronic -	10						
acute -	19						
Cyanide (amenable to chlorination)							
chronic toxicity	5						
acute toxicity	22						
Hydrogen sulfide	2						

Pollutant (mg/l)	**I**	**II**	**III**	**IV**	**V**	**VI**	**VII**
chloride chronic -	230		250				
acute -	860						
sulfate			250				
fluoride			4		4		4
Nitrate -N			10				10
Dissolved oxygen (minimum)							
warm- & cool-water fisheries	5						
cold-water fisheries	6						
oil & grease	10						

Pollutant (/100 ml)	**I**	**II**	**III**	**IV**	**V**	**VI**	**VII**
Fecal Coliform Bacteria						200	

Pollutant (^{0}F)	**I**	**II**	**III**	**IV**	**V**	**VI**	**VII**
Temperature (maximum)							
warm-water	90						
cool-water	84						
cold-water	68						
Temp. (maximum change)							
warm-water	5						
cool-water	5						
cold-water	2						

Pollutant (% saturation)	**I**	**II**	**III**	**IV**	**V**	**VI**	**VII**
Total dissolved gases	110						

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Pollutant (g/l)	**I**			**II**	**III**	**IV**	**V**	**VI**	**VII**
METALS									
Aluminum (acute)	750								
Antimony				4300	6				6
Arsenic	20				50	100			50
Barium					2000				2000
Beryllium	5				4	100			4
Boron						2000			2000
Cadmium	Hardness				5				5
	<125	125-200	>200						
chronic:									
CWF	1.2	1.5	2						
Lakes	10	10	10						
GWWF	10	13	17						
LWWF	13	18	22						
acute:									
CWF	3.9	6.2	8.6						
Lakes & GWWF	33	52	72						
LWWF	46	72	100						
Chromium					100	100			100
chronic:									
Lakes	11								
CWF,GWWF	42								
LWWF	190								
acute:									
Lakes	16								
CWF & GWWF	62								
LWWF	280								
Cobalt						1000		1000	
Copper	Hardness								
	<125	125-200	>200		1300		500		1300
chronic:									
Lakes,CWF,GWWF	20	29	37						
LWWF	30	43	55						
acute:									
Lakes,CWF,GWWF	30	45	58						
LWWF	46	67	88						
Iron	1000			300	300				
Lead	Hardness			15	15				
	<125	125-200	>200						
chronic:									
all waters	12	20	29						
acute:									
all waters	80	130	190						

CWF = Cold-water fishery
GWWF = General warm-water fishery
LWWF = Limited warm-water fishery

I = Protection of Aquatic Life
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Pollutant (g/l)	**I**			**II**	**III**	**IV**	**V**	**VI**	**VII**
Manganese					50				50
Mercury					2				2
chronic:									
all waters	0.5								
acute:									
all waters	2.4								
Nickel			Hardness		100				100
		<125	125-200	>200					
chronic:									
Lakes		160	220	280					
CWF,GWWF		360	500	650					
LWWF		425	600	770					
acute:									
Lakes		1400	2000	2500					
CWF,GWWF		3200	4600	5800					
LWWF		3800	5400	6900					
Selenium	5				50				50
Silver			Hardness		50				50
		<125	125-200	>200					
acute:									
all waters		4.1	8.2		13				
Thallium						6.3	2		
2									
Zinc			Hardness			5000			5000
		<125	125-200	>200					
chronic:									
CWF		175	240	310					
Lakes		105	150	190					
GWWF		245	345	440					
LWWF		1065	1505	1920					
acute:									
CWF		190	270	345					
Lakes		115	165	210					
GWWF		270	380	490					
LWWF		1180	1660	2120					

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Pollutant (g/l)	**I**	**II**	**III**	**IV**	**V**	**VI**	**VII**
Organics							
Acenaphthene		2700	20				20
Acrolein		780	320				320
Bis-2-chloroisopropyl ether		4360	35				35
2,chlorophenol		400	0.1				0.1
2,4-dichlorophenol	7	790	93				93
2,4-dinitrophenol		14000	70				70
2,4-dimethylphenol		2300	540				540
2,4,5-trichlorophenol		9800	1				1
2,4,6-trichlorophenol		7	2				2
2-methyl-4,6-dinitrophenol		765	13				13
Ethylbenzene	320		700				700
Hexachlorocyclopentadiene	0.5		50				50
Isophorone		2600	36				36
Nitrobenzene		1900	17				17
Phenol 100		1				300	
Dichloropropene		1700	10				10
Fluoranthene		54	40				40
Para(1,4)-dichlorobenzene		2600	75				75
Other Dichlorobenzenes		2600	400				400
1,2,4-trichlorobenzene		940	70				70
1,2,4,5-tetrachlorobenzene		2.9	2.3				2.3
Pentachlorobenzene		85	74				74
1,1,1-trichloroethane			200				200
1,1,2-trichloroethane		42	5				5
2,4-dinitrotoluene		9	0.11				0.11
1,2-diphenylhydrazine		0.54	0.04				0.04
di(2-ethylhexyl)adipate			400				400
n-nitrosodiphenylamine		16	5				5
n-nitrosopyrrolidene		93					
2-chloronaphthalene	4300						
n-nitrosodi-n-propylamine		1.4					

Pollutant (g/l)	**I**	**II**	**III**	**IV**	**V**	**VI**	**VII**
Pesticides							
Demeton	0.1						
Endosulfan							
chronic -	0.056						
acute -	0.11						
Guthion	0.01						
Malathion	0.1						
Parathion	0.04						
2,4-D			70				70
2,4,5-TP			50				50
Chlorphyrifos	0.04						
Alachlor			2				2
Atrazine			3				3
Carbofuran			40				40
Dalapon			200				200
Dibromochloropropane			0.2				0.2
Dinoseb			7				7
Diquat		20				20	
Endothall			100				100
Ethylene dibromide			0.05				0.05
Oxamyl(vydate)			200				200
Picloram			500				**500**
Simazine			4				4

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Pollutant (g/l)	**I**	**II**	**III**	**IV**	**V**	**VI**	**VII**
Persistent, Bioaccumulative, Man-Made Toxics							
PCBs		.000045					.000045
DDT and metabolites		.000024					.000024
Endrin		.0023	2				2
Endrin aldehyde		.0023	.75				.75
Aldrin		.000079	.000074				.000074
Dieldrin			.000076	.000071			
.000071							
Heptachlor	.0038	.0002	.4				.4
Heptachlor epoxide		.00011	.2				.2
Methoxychlor	.03		40				40
Mirex	.001						
Toxaphene		.000073	3				3
Lindane(gamma-BHC)		.062	.2				.2
Alpha,beta,delta-BHC		.0074	.0022				.0022
Chlordane		.00048	2				2
Benzidine		.00053	.00012				.00012
3,7,8-TCDD(dioxin)(nanograms/l)		.000014	.03				.03
Pentachlorophenol	3.2-pH 6.5 5.3-pH 7.0 8.7-pH 7.5 14- pH 8.0 23- pH 8.5		1				1

Pollutant (g/l)	**I**	**II**	**III**	**IV**	**V**	**VI**	**VII**
Polynuclear Aromatic Hydrocarbons							
Anthracene		110,000	9600				9600
Fluoranthene		370	300				300
Fluorene		14,000	1300				1300
Pyrene		11,000	960				960
Benzo(a)pyrene		.049	0.2				0.2
Other polynuclear aromatic hydrocarbons		.049	.0044				.0044

Pollutant (g/l)	**I**	**II**	**III**	**IV**	**V**	**VI**	**VII**
Phthalate Esters							
Bis(2-ethylhexyl)phthalate		5.9	6				6
Butylbenzylphthalate		5200	3000				3000
Methylphthalate		120,000	23,000				23,000
Dimethyl phthalate		2,900,000	313,000				313,000
Di-n-butylphthalate		12,000	2700				2700

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Pollutant (g/l)	**I**	**II**	**III**	**IV**	**V**	**VI**	**VII**
Persistent, Manmade Carcinogens							
Acrylonitrile		.65	.058				.058
Hexachlorobenzene		.00074	1				1
Bis(2-chloroethyl)ether		1.4	.03				.03
Bis(chloromethyl)ether		.07	.00016				.00016
Hexachloroethane		8.7	1.9				1.9
3,3'-dichlorobenzidine		.08	.04				.04
Hexachlorobutadiene		50	.45				.45
N-nitrosodimethylamine		8	.0007				.0007

Pollutant (g/l)	**I**	**II**	**III**	**IV**	**V**	**VI**	**VII**
Volatile Organics							
Chlorobenzene		21000	100				100
Carbon Tetrachloride		5	5				5
Trihalomethanes			100				100
Methyl Bromide		4000	48				48
Methyl Chloride		470	5				5
Methylene Chloride		1600	5				5
Bromoform		365					
Chlorodibromomethane		35					
Dichlorobromomethane		46					
Dichlorodifluoromethane		570000					
Trichlorofluoromethane		860000					
1,2-dichloroethane		99	5				5
1,1,2,2-tetrachloroethane		11	.17				.17
1,1-dichloroethylene		3.2	7				7
1,2-trans-dichloroethylene		140000	100				100
Trichloroethylene		80	5				5
Tetrachloroethylene		9	5				5
Benzene		71	5				5
Toluene		200000	1000				1000
Xylenes(total)			10000				10000
Vinyl chloride			525	2			
2							
Styrene			100				100
1,2-dichloropropane		39	100				100

Pollutant (fibers/l)	**I**	**II**	**III**	**IV**	**V**	**VI**	**VII**
Asbestos			7000000				